



Advanced Automotive Fault Diagnosis

Third Edition

Tom Denton

Automotive Technology: Vehicle Maintenance and Repair

ROUTLEDGE



Advanced Automotive Fault Diagnosis

Third Edition

Automotive Technology: Vehicle Maintenance and Repair









Advanced Automotive Fault Diagnosis

Third Edition

Automotive Technology:
Vehicle Maintenance and Repair



Tom Denton BA FIMI MSAE
MIRTE Cert Ed

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

First published 2012
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

Simultaneously published in the USA and Canada
by Routledge
711 Third Avenue, New York, NY 10017

Routledge is an imprint of the Taylor & Francis Group, an informa business

© 2012 Tom Denton. All rights reserved

The right of Tom Denton to be identified as author of this work has been asserted by him/her in accordance with sections 77 and 78 of the Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this book may be reprinted or reproduced or utilised in any form or by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying and recording, or in any information storage or retrieval system, without permission in writing from the publishers.

Trademark notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging in Publication Data
A catalog record for this title has been requested

ISBN: 978-0-08-096955-8
ISBN: 978-0-08-096956-5 (ebk)

Typeset in Helvetica

by MPS Limited, a Macmillan Company, Chennai, India

Contents

Preface xix
Acknowledgements xxi

Chapter 1 Introduction 1

1.1 Diagnosis 1
1.1.1 Introduction 1
1.2 Safe working practices 2
1.2.1 Risk assessment and reduction 2
1.3 Terminology 2
1.3.1 Introduction 2
1.3.2 Diagnostic terminology 3
1.3.3 General terminology 4
1.4 Report writing 4
1.4.1 Introduction 4
1.4.2 Main headings of a report 5
1.4.3 Example report 6

Chapter 2 Diagnostic techniques 9

2.1 Introduction 9
2.1.1 Logic 9
2.1.2 Information 9
2.1.3 Where to stop? 9
2.2 Diagnostic process 10
2.2.1 Six-stage process 10
2.2.2 The art of diagnostics 11
2.2.3 Concern, cause, correction 12
2.2.4 Root cause analysis 13
2.2.5 Summary 15
2.3 Diagnostics on paper 16
2.3.1 Introduction 16
2.3.2 Examples 16
2.3.3 How long is a piece of string? 17
2.4 Mechanical diagnostic techniques 17
2.4.1 Check the obvious first 17
2.4.2 Noise, vibration and harshness 17
2.4.3 Noise conditions 18

2.4.4 Vibration conditions 19
2.4.5 Road test 19
2.4.6 Engine noises 20
2.4.7 Sources of engine noise 21
2.5 Electrical diagnostic techniques 22
2.5.1 Check the obvious first 22
2.5.2 Test lights and analogue meters – warning 22
2.5.3 Generic electrical testing procedure 23
2.5.4 Volt drop testing 24
2.5.5 Testing for short circuits to earth 24
2.5.6 On and off load tests 25
2.5.7 Black box technique 25
2.5.8 Sensor to ECU method 26
2.5.9 Flight recorder tests 26
2.5.10 Faultfinding by luck – or is it logic? 27
2.5.11 Colour codes and terminal numbers 28
2.5.12 Back probing connectors 30
2.6 Fault codes 31
2.6.1 Fast and slow 31
2.6.2 Fault code examples 32
2.6.3 Clearing 33
2.7 Systems 34
2.7.1 What is a system? 34
2.7.2 Vehicle systems 34
2.7.3 Open-loop systems 35
2.7.4 Closed-loop systems 35
2.7.5 Block diagrams 36
2.8 Data sources 36
2.8.1 Introduction 36
2.8.2 Autodata 38
2.8.3 Bosch ESItronic 38
2.9 Summary 41

Chapter 3 Tools and equipment 43

3.1 Basic equipment 43
3.1.1 Introduction 43
3.1.2 Basic hand tools 43
3.1.3 Accuracy of test equipment 43
3.1.4 Multimeters 45
3.1.5 Logic probe 47
3.2 Oscilloscopes 47

3.2.1 Introduction 47
3.2.2 Waveforms 49
3.3 Scanners/Fault code readers and analysers 50
3.3.1 On-board diagnostics introduction 50
3.3.2 Serial port communications 50
3.3.3 OBD2 signal protocols 51
3.3.4 AutoTap OBD scanner 52
3.3.5 Bosch KTS diagnostic equipment 53
3.3.6 Engine analysers 55
3.4 Emission testing 59
3.4.1 Introduction 59
3.4.2 Exhaust gas measurement 59
3.4.3 Exhaust analyser 60
3.4.4 Emission limits 60
3.5 Pressure testing 62
3.5.1 Introduction 62
3.5.2 Automotive pressure oscilloscope transducer 64

Chapter 4 Sensors, actuators and oscilloscope diagnostics 67

4.1 Introduction 67
4.2 Sensors 67
4.2.1 Introduction and sensor diagnostics 67
4.2.2 Inductive sensors 69
4.2.3 Variable resistance 74
4.2.4 Hot wire airflow sensor 77
4.2.5 Thermistors 78
4.2.6 Hall effect sensors 80
4.2.7 Piezo accelerometer 82
4.2.8 Oxygen sensors 84
4.2.9 Pressure sensors 87
4.2.10 Variable capacitance 89
4.2.11 Optical sensors 91
4.2.12 Dynamic position sensors 92
4.2.13 Rain sensor 93
4.3 Actuators 93
4.3.1 Introduction 93
4.3.2 Testing actuators 94
4.3.3 Motorised and solenoid actuators 94
4.3.4 Solenoid actuators 98
4.3.5 Thermal actuators 106
4.4 Engine waveforms 106

4.4.1 Ignition primary 106
4.4.2 Ignition secondary 108
4.4.3 Diesel glow plugs 110
4.4.4 Alternator waveform 111
4.4.5 Relative compression petrol 112
4.5 Communication networks 113
4.5.1 CAN 113
4.5.2 LIN 116
4.5.3 FlexRay 116
4.6 Summary 118

Chapter 5 On-board diagnostics 119

5.1 History 119
5.1.1 Introduction 119
5.1.2 Vehicle emissions and environmental health 119
5.1.3 History of the emissions control legislation 120
5.1.4 Introduction of vehicle emissions control strategies 122
5.2 What is on-board diagnostics? 123
5.2.1 OBD scenario example 123
5.2.2 Origins of OBD in the United States 124
5.2.3 P-code composition 125
5.2.4 European on-board diagnostics and global adoption 126
5.2.5 Summary 126
5.3 Petrol/Gasoline on-board diagnostic monitors 127
5.3.1 Introduction 127
5.3.2 Legislative drivers 127
5.3.3 Component monitoring 127
5.3.4 Rationality testing 128
5.3.5 Circuit testing 128
5.3.6 Catalyst monitor 128
5.3.7 Evaporative system monitor 129
5.3.8 Fuel system monitoring 130
5.3.9 Exhaust gas recirculation monitor 132
5.3.10 Secondary air monitor 133
5.3.11 Monitors and readiness flags 134
5.4 Misfire detection 135
5.4.1 Misfire monitor 135
5.4.2 Crank speed fluctuation 138
5.4.3 Ionising current monitoring 138

5.4.4 Cylinder pressure sensing 140
5.4.5 Exhaust pressure analysis 140
5.5 OBD summary 140
5.5.1 OBD2 141
5.5.2 EOBD 142
5.5.3 Features and technology of current systems 144
5.6 Driving cycles 145
5.6.1 Introduction 145
5.6.2 Europe 145
5.6.3 United States 146
5.7 Future developments in diagnostic systems 147
5.7.1 OBD3 147
5.7.2 Diesel engines 148
5.7.3 Rate-based monitoring 148
5.7.4 Model-based development 148
5.8 Summary 149

Chapter 6 Engine systems 151

6.1 Introduction 151
6.2 Engine operation 151
6.2.1 Four-stroke cycle 151
6.2.2 Cylinder layouts 153
6.2.3 Camshaft drives 153
6.2.4 Valve mechanisms 153
6.2.5 Valve and ignition timing 155
6.3 Diagnostics – engines 156
6.3.1 Systematic testing example 156
6.3.2 Test equipment 156
6.3.3 Test results 157
6.3.4 Engine fault diagnosis table 1 158
6.3.5 Engine fault diagnosis table 2 158
6.4 Fuel system 160
6.4.1 Introduction 160
6.4.2 Carburation 161
6.5 Diagnostics – fuel system 165
6.5.1 Systematic testing example 165
6.5.2 Test equipment 166
6.5.3 Test results 166
6.5.4 Fuel fault diagnosis table 1 167
6.5.5 Fuel fault diagnosis table 2 167
6.6 Introduction to engine management 168

6.7 Ignition 168
6.7.1 Basics 168
6.7.2 Advance angle (timing) 168
6.7.3 Electronic ignition 169
6.7.4 Hall effect distributor 170
6.7.5 Inductive distributor 171
6.7.6 Current-limiting and closed-loop dwell 171
6.7.7 Programmed ignition/electronic spark advance 172
6.7.8 Distributorless ignition 175
6.7.9 Direct ignition 176
6.7.10 Spark plugs 177
6.8 Diagnostics – ignition system 179
6.8.1 Testing procedure 179
6.8.2 Ignition fault diagnosis table 181
6.8.3 Ignition components and testing 181
6.8.4 DIS diagnostics 183
6.8.5 Spark plugs 183
6.9 Emissions 185
6.9.1 Introduction 185
6.9.2 Exhaust gas recirculation 186
6.9.3 Catalytic converters 186
6.10 Diagnostics – emissions 187
6.10.1 Testing procedure 187
6.10.2 Emissions fault diagnosis table 189
6.11 Fuel injection 189
6.11.1 Introduction 189
6.11.2 Injection systems 190
6.11.3 Fuel injection components 191
6.11.4 Fuel mixture calculation 193
6.12 Diagnostics – fuel injection systems 194
6.12.1 Testing procedure 194
6.12.2 Fuel injection fault diagnosis table 194
6.13 Diesel injection 195
6.13.1 Introduction 195
6.13.2 Electronic control of diesel injection 197
6.13.3 Common rail diesel systems 198
6.13.4 Diesel exhaust emissions 200
6.13.5 Catalytic converter diesel 200
6.13.6 Filters 201
6.14 Diagnostics – diesel injection systems 201
6.14.1 Test equipment 201

6.14.2 Diesel injection fault diagnosis table 202
6.14.3 Diesel engine smoke 202
6.14.4 Glow plug circuit 204
6.14.5 Diesel systems 204
6.15 Engine management 205
6.15.1 Introduction 205
6.15.2 Closed-loop lambda control 206
6.15.3 Engine management operation 206
6.15.4 Gasoline direct injection 212
6.16 Diagnostics – combined ignition and fuel systems 213
6.16.1 Testing procedure 213
6.16.2 Combined ignition and fuel control fault diagnosis table 215
6.16.3 Fuel pump testing 217
6.16.4 Injector testing 218
6.17 Engine management and fault finding information 219
6.17.1 Diagnosis charts 219
6.17.2 Circuit diagrams 219
6.17.3 Component testing data 219
6.18 Air supply and exhaust systems 219
6.18.1 Exhaust system 219
6.18.2 Catalytic converters 222
6.18.3 Air supply system 224
6.19 Diagnostics – exhaust and air supply 225
6.19.1 Systematic testing 225
6.19.2 Test results 225
6.19.3 Exhaust and air supply fault diagnosis table 1 225
6.19.4 Exhaust fault diagnosis table 2 226
6.20 Cooling 226
6.20.1 Air-cooled system 226
6.20.2 Water-cooled system 226
6.20.3 Sealed and semi-sealed systems 227
6.21 Diagnostics – cooling 228
6.21.1 Systematic testing 228
6.21.2 Test equipment 229
6.21.3 Test results 229
6.21.4 Cooling fault diagnosis table 1 230
6.21.5 Cooling fault diagnosis table 2 230
6.22 Lubrication 230
6.22.1 Lubrication system 230
6.22.2 Oil filters 231

6.22.3 Oil pumps 232
6.22.4 Crankcase ventilation engine breather systems 233
6.23 Diagnostics – lubrication 233
6.23.1 Systematic testing 233
6.23.2 Test equipment 234
6.23.3 Test results 234
6.23.4 Lubrication fault diagnosis table 1 234
6.23.5 Lubrication fault diagnosis table 2 235
6.24 Batteries 235
6.24.1 Safety 235
6.24.2 Lead-acid batteries 235
6.24.3 Battery rating 236
6.25 Diagnostics – batteries 237
6.25.1 Servicing batteries 237
6.25.2 Maintenance-free 238
6.25.3 Charging 238
6.25.4 Battery faults 239
6.25.5 Testing batteries 240
6.26 Starting 243
6.26.1 Starter circuit 243
6.26.2 Inertia starters 243
6.26.3 Pre-engaged starters 244
6.26.4 Permanent magnet starters 245
6.26.5 Keyless starting system 247
6.27 Diagnostics – starting 248
6.27.1 Circuit testing procedure 248
6.27.2 Starting fault diagnosis table 248
6.28 Charging 249
6.28.1 Introduction 249
6.28.2 Basic principles 251
6.28.3 Rectification of AC to DC 251
6.28.4 Regulation of output voltage 253
6.28.5 Charging circuits 253
6.29 Diagnostics – charging 256
6.29.1 Testing procedure 256
6.29.2 Charging fault diagnosis table 256

Chapter 7 Chassis systems 257

7.1 Brakes 257
7.1.1 Introduction 257
7.1.2 Principle of hydraulic braking 258

7.1.3 Disc and drum brake systems 259
7.1.4 Brake adjustments 260
7.1.5 Servo-assisted braking 260
7.2 Diagnostics – brakes 261
7.2.1 Systematic testing 261
7.2.2 Test equipment 261
7.2.3 Dial gauge 262
7.2.4 Test results 262
7.2.5 Brakes fault diagnosis table 1 263
7.2.6 Brakes fault diagnosis table 2 263
7.2.7 Brake hydraulic faults 264
7.3 Antilock brakes 264
7.3.1 Introduction 264
7.3.2 General system description 266
7.3.3 ABS components 266
7.4 Diagnostics – antilock brakes 269
7.4.1 Systematic testing procedure 269
7.4.2 Antilock brakes fault diagnosis table 270
7.4.3 Bleeding antilock brakes 271
7.5 Traction control 271
7.5.1 Introduction 271
7.5.2 Control functions 272
7.5.3 System operation 272
7.6 Diagnostics – traction control 272
7.6.1 Systematic testing 272
7.6.2 Traction control fault diagnosis table 274
7.7 Steering and tyres 274
7.7.1 Construction of a tubeless radial tyre 274
7.7.2 Steering box and rack 274
7.7.3 Power-assisted steering 275
7.7.4 Steering characteristics 276
7.7.5 Camber 277
7.7.6 Castor 277
7.7.7 Swivel axis inclination 278
7.7.8 Tracking 279
7.7.9 Scrub radius 279
7.8 Diagnostics – steering and tyres 280
7.8.1 Systematic testing 280
7.8.2 Test equipment 280
7.8.3 Four-wheel alignment 281
7.8.4 Test results 283

7.8.5 Tyres fault diagnosis table 284
7.8.6 Tyre inflation pressures 284
7.8.7 Steering fault diagnosis table 1 285
7.8.8 Steering, wheels and tyres fault diagnosis 285
7.9 Suspension 286
7.9.1 Introduction 286
7.9.2 Suspension system layouts 286
7.9.3 Front axle suspensions 288
7.9.4 Rear axle suspensions 289
7.9.5 Anti-roll bar 289
7.9.6 Springs 290
7.9.7 Dampers 290
7.10 Diagnostics – Suspension 293
7.10.1 Systematic testing 293
7.10.2 Test equipment 293
7.10.3 Test results 293
7.10.4 Suspension fault diagnosis table 1 294
7.10.5 Suspension fault diagnosis table 2 294
7.11 Active Suspension 294
7.11.1 Active suspension operation 294
7.11.2 Delphi MagneRide case study 297
7.12 Diagnostics – active suspension 299
7.12.1 Systematic testing 299
7.12.2 Back to the black box 300

Chapter 8 Electrical systems 301

8.1 Electronic components and circuits 301
8.1.1 Introduction 301
8.1.2 Components 301
8.1.3 Integrated circuits 303
8.1.4 Digital circuits 304
8.1.5 Electronic component testing 305
8.2 Multiplexing 306
8.2.1 Overview 306
8.2.2 Controller area network 307
8.2.3 CAN data signal 310
8.2.4 Local interconnect network 311
8.2.5 FlexRay 312
8.3 Diagnostics – multiplexing 312
8.4 Lighting 316
8.4.1 External lights 316
8.4.2 Lighting circuits 317

8.4.3 Gas discharge lighting 318
8.4.4 LED lighting 319
8.5 Diagnostics – lighting 321
8.5.1 Testing procedure 321
8.5.2 Lighting fault diagnosis table 323
8.5.3 Headlight beam setting 324
8.6 Auxiliaries 325
8.6.1 Wiper motors and linkages 325
8.6.2 Wiper circuits 327
8.6.3 Two-motor wiper system 328
8.6.4 Headlight wipers and washers 328
8.6.5 Indicators and hazard lights 329
8.6.6 Brake lights 329
8.6.7 Electric horns 330
8.6.8 Engine cooling fan motors 331
8.7 Diagnostics – auxiliary 332
8.7.1 Testing procedure 332
8.7.2 Auxiliaries fault diagnosis table 334
8.7.3 Wiper motor and circuit testing 334
8.8 In-car entertainment security and communications 336
8.8.1 In-car entertainment 336
8.8.2 Security systems 338
8.8.3 Mobile communications 339
8.9 Diagnostics – ICE, security and communication 339
8.9.1 Testing procedure 339
8.9.2 ICE, security and communication system fault diagnosis table 341
8.9.3 Interference suppression 342
8.10 Body electrical systems 344
8.10.1 Electric seat adjustment 344
8.10.2 Electric mirrors 345
8.10.3 Electric sunroof operation 345
8.10.4 Door locking circuit 346
8.10.5 Electric window operation 347
8.11 Diagnostics – body electrical 348
8.11.1 Testing procedure 348
8.11.2 Body electrical systems fault diagnosis table 350
8.11.3 Circuit systematic testing 350
8.12 Instrumentation 351
8.12.1 Gauges 351
8.12.2 Digital instrumentation 352
8.12.3 Vehicle condition monitoring 353

8.12.4 Trip computer 355
8.12.5 Displays 355
8.13 Diagnostics – instruments 356
8.13.1 Testing procedure 356
8.13.2 Instrumentation fault diagnosis table 356
8.13.3 Black box technique for instrumentation 356
8.14 Heating, ventilation and air conditioning 359
8.14.1 Ventilation and heating 359
8.14.2 Heating system – water-cooled engine 359
8.14.3 Heater blower motors 360
8.14.4 Electronic heating control 360
8.14.5 Air conditioning introduction 361
8.14.6 Air conditioning overview 363
8.14.7 Automatic temperature control 363
8.14.8 Seat heating 364
8.14.9 Screen heating 364
8.15 Diagnostics – HVAC 365
8.15.1 Testing procedure 365
8.15.2 Air conditioning fault diagnosis table 365
8.15.3 Heating and ventilation fault diagnosis table 367
8.15.4 Air conditioning receiver 367
8.16 Cruise control 367
8.16.1 Introduction 367
8.16.2 System description 368
8.16.3 Components 369
8.17 Diagnostics – cruise control 369
8.17.1 Systematic testing 369
8.17.2 Cruise control fault diagnosis table 371
8.18 Airbags and belt tensioners 371
8.18.1 Introduction 371
8.18.2 Components and circuit 372
8.18.3 Seat belt tensioners 374
8.19 Diagnostics – airbags and belt tensioners 375
8.19.1 Systematic testing 375
8.19.2 Airbags and belt tensioners fault diagnosis table 375
8.19.3 Deactivation and activation procedures 375

Chapter 9 Transmission systems 379

9.1 Manual transmission 379
9.1.1 Clutch 379
9.1.2 Manual gearbox 380

9.1.3 Driveshafts and wheel bearings 381
9.1.4 Final drive and differential 384
9.1.5 Four-wheel drive systems 384
9.2 Diagnostics – manual transmission 385
9.2.1 Systematic testing 385
9.2.2 Test equipment 385
9.2.3 Test results 385
9.2.4 Manual transmission fault diagnosis table 1 386
9.2.5 Manual gearbox fault diagnosis table 2 386
9.2.6 Clutch faults diagnosis table 387
9.2.7 Drive shafts fault diagnosis table 387
9.2.8 Final drive fault diagnosis table 387
9.3 Automatic transmission 388
9.3.1 Introduction 388
9.3.2 Torque converter operation 388
9.3.3 Epicyclic gearbox operation 389
9.3.4 Constantly variable transmission 390
9.3.5 Electronic control of transmission 391
9.3.6 Direct shift gearbox 393
9.4 Diagnostics – automatic transmission 395
9.4.1 Systematic testing 395
9.4.2 Test equipment 395
9.4.3 Test results 395
9.4.4 Automatic gearbox fault diagnosis table 1 396
9.4.5 Automatic gearbox fault diagnosis table 2 397
9.4.6 ECAT fault diagnosis table 397
9.4.7 Automatic transmission stall test 397

Chapter 10 Learning activities 399

10.1 Introduction 399
10.2 Knowledge check questions 399
10.2.1 Chapter 1 Introduction 399
10.2.2 Chapter 2 Diagnostic techniques 400
10.2.3 Chapter 3 Tools and equipment 400
10.2.4 Chapter 4 Sensors, actuators and oscilloscope diagnostics 400
10.2.5 Chapter 5 On-board diagnostics 400
10.2.6 Chapter 6 Engine systems 401
10.2.7 Chapter 7 Chassis systems 401
10.2.8 Chapter 8 Electrical systems 401
10.2.9 Chapter 9 Transmission systems 401

10.3 Assignments 402
10.4 Tips to help you learn 403
10.5 Practical work 404
10.6 Case studies 404
10.6.1 Introduction 404
10.6.2 1997 Land Rover Discovery 405
10.6.3 1999 Audi A4 Quattro 406
10.6.4 2002 Ford Ranger 407
10.6.5 2005 Volkswagen Jetta 407
10.6.6 2004 Honda Accord 408
10.6.7 Summary 409
10.7 Software 409
10.8 Summary 409

Glossary of abbreviations and acronyms 411
Index 423

Preface

One of the things that I most enjoy about automotive work is being able to diagnose problems that others cannot. This skill takes a few years to develop, but it is really all about two things: knowledge of the vehicle system and an understanding of the importance of a logical diagnostic process. In this book, I have therefore included some basic technologies (as a reminder) and then examined appropriate diagnostic techniques.

This book is the third in the "Automotive Technology: Vehicle Maintenance and Repair" series:

- Automobile Mechanical and Electrical Systems
- Automobile Electrical and Electronic Systems
- Automobile Advanced Fault Diagnosis

Ideally, you will have studied the mechanical and electrical book, or have some experience, before starting on this one. This is the first book of its type to be published in full colour and concentrates on diagnostic principles. It will cover everything you need to advance your studies to a higher level, no matter what qualification (if any) you are working towards.

I hope you find the content useful and informative. Comments, suggestions and feedback are always welcome at my website: www.automotive-technology.co.uk. You will also find links to lots of free online resources to help with your studies.

The final chapter of this book contains lots of learning activities, questions, diagnostic case studies and more. You can look at this at any time or wait until you have studied the rest of the book.

Good luck and I hope you find automotive technology as interesting as I still do.

Acknowledgements

Over the years many people have helped in the production of my books. I am therefore very grateful to the following companies that provided information and/or permission to reproduce photographs and/or diagrams:

AA Photo Library
AC Delco
Alpine Audio Systems
ATT Training (UK and USA)
Autologic Data Systems
BMW UK
Bosch Media
C&K Components Inc.
Citroën UK
Clarion Car Audio
Delphi Media
Eberspaecher
Fluke Instruments UK
Ford Motor Company
Ford Media
General Motors
GenRad
Hella UK
Honda Cars UK
Hyundai UK
Jaguar Cars
Kavlico
Loctite
Lucas UK
LucasVarity
Mazda Cars UK
McLaren Electronic Systems
Mercedes Cars UK
Mitsubishi Cars UK
NGK Plugs
Nissan Cars UK
Peugeot UK
Philips
PicoTech
Pioneer Radio
Porsche Cars UK
Robert Bosch GmbH
Robert Bosch UK
Rover Cars
Saab Cars UK
Saab Media
Scandmec
Snap-on Tools

Sofanou (France)
Sun Electric UK
Thrust SSC Land Speed Team
T&M Auto-Electrical
Toyota Cars UK
Tracker UK
Unipart Group
Valeo UK
Vauxhall UK
VDO Instruments
Volvo Media
Volkswagen cars
Wikimedia
ZF Servomatic

If I have used any information, or mentioned a company name that is not listed here, please accept my apologies and let me know so it can be rectif ed as soon as possible.

CHAPTER

Introduction

1.1 Diagnosis

1.1.1 Introduction

What is needed to f nd faults?

Finding the problem when complex automotive systems go wrong is easy if you have the necessary knowledge. This knowledge consists of two parts:

- understanding of the system in which the problem exists;
- the ability to apply a logical diagnostic routine.

It is also important to be clear about these def nitions:

- symptom(s) – what the user/operator/repairer of the system (vehicle or whatever) notices;
- fault(s) – the error(s) in the system that result in the symptom(s);
- root cause(s) – the cause(s) of the fault.

If a system is not operating to its optimum, then it should be repaired. This is where diagnostic and other skills come into play. It is necessary to recognise that something is not operating correctly by applying your knowledge of the system, and then by applying this knowledge further, and combining it with the skills of diagnostics, to be able to f nd out the reason.

The four main chapters of this book ('Engine systems', 'Chassis systems', 'Electrical systems' and 'Transmission systems') include a basic explanation of the vehicle systems followed by diagnostic techniques that are particularly appropriate for that area. Examples of faultf nding charts are also included. In the main text, references will be made to generic systems rather than to specif c vehicles or marques. For specif c details about a particular vehicle or system, the manufacturer's information is the main source.

Other chapters such as 'Sensors, actuators and oscilloscope diagnostics' and 'On-board diagnostics' are separated from the four previously mentioned chapters, because many operations are the same. For example, testing an inductive sensor is similar whether it is used on ABS or engine management.

An important note about diagnostics is that the general principles and techniques can be applied to any system, physical or otherwise. As far as passenger-carrying heavy or light vehicles are concerned, this is def nitely the case. As discussed earlier, there is a need for knowledge of the particular system, but diagnostic skills are transferable (Figure 1.1).



Def nition

Diagnosis: The word 'diagnosis' comes from the ancient Greek word διάγνωσις', which means discernment. It is the identification of the nature and cause of anything. Diagnosis is used in many different disciplines, but all use logic, analysis and experience to determine cause and effect relationships. In automotive engineering, diagnosis is typically used to determine the causes of symptoms and solutions to issues.



Key fact

General diagnostic principles and techniques can be applied to any system, physical or otherwise.

Advanced Automotive Fault Diagnosis.
© 2012 Tom Denton. Published by Routledge. All rights reserved.



Figure 1.1 Diagnostics in action

1.2 Safe working practices

Safe working practices in relation to diagnostic procedures and indeed any work on a vehicle are essential – for your safety as well as that of others. You only have to follow two rules to be safe:

Use your common sense – do not fool about.

If in doubt – seek help.

Further, always wear appropriate personal protective equipment (PPE) when working on vehicles.

Safety f rst

Always wear appropriate personal protective equipment (PPE) when working on vehicles.

The following section lists some particular risks when working with vehicle systems, together with suggestions for reducing them. This is known as risk assessment.

1.2.1 Risk assessment and reduction

Table 1.1 lists some identif ed risks involved with working on vehicles. The table is by no means exhaustive but serves as a good guide.

1.3 Terminology

1.3.1 Introduction

The terminology included in Tables 1.2 and 1.3 is provided to ensure we are talking the same language. These tables are provided as a simple reference source.

Table 1.1 Identifying and reducing risk

Identif edrisk	Reducing the risk
Battery acid	Sulphuric acid is corrosive, so always use good PPE – in this case overalls and if ecessar ynrubber gloves. A rubber apron is ideal as are goggles if working with batteries a lot, particularly older types
Electric shock	Ignition HT is the most likely place to suffer a shock – up0 0 0 2 5 is quite normal. Use insulated tools if it is necessaryto work on HT circuits with the engine running. Note that high voltages are also present on circuits containing windings due to back emf as they are switched off – a few hundred volts is common. Mains supplied power tools and their leads should be in good condition, and using an earth leakage trip is highly recommended
Exhaust gases	Suitable extraction must be used if the engine is running indoors. Remember it is not just the C that might make you ill or even kill you, other exhaust components could also cause asthma or even cancer
Fire	Do not smoke when working on a vehicle. Fuel leaks must be attended to immediately Remember the triangle ofre – (heat/fuel/oxygen) – do not let the three sides come together
Moving loads	Only lift what is comfortable for you; ask for help if neces yand/or use lifting equipment. As a general guide, do not lift on your own if it feels too heavy
Raising or lifting vehicles	Apply brakes and/or chock the wheels when raising a vehicle on a jack or drive on lift. Only jac under substantial chassis and suspension structures. Use axle stands in case the jack fails
Running engines	Do not wear loose clothing – good overalls are ideal. Keep the keys in your possession when working on an engine to prevent others starting ikeTextra care if working near running drive belts
Short circuits	Use a jump lead with an in-line fuse to prevent damage due to a short when testing. Disconnec the battery (earth lead offrst and back on last) if any danger of a short exists. yA higher current can fow from a vehicle batter– it will burn you as well as the vehicle
Skin problems	Use a good barrier cream and/or latex glovesash Wskin and clothes regularly

1.3.2 Diagnostic terminology

Table 1.2 Diagnostic terminology

Symptom	The effect of a fault noticed by the driverser or technician
Fault	The cause of a symptom/problem
Root cause	This may be the same as the fault, but in some cases it can be the cause of it
Diagnostics	The process of tracing a fault by means of its symptoms, applying knowledge and analysing test results
Knowledge	The understanding of a system that is required to diagnose faults
Logical procedure	A step-by-step method used to ensure nothing is missed
Concern, cause, correction	A reminder of the process starting from what the driver reports, to the correction of the problem
Report	A standard format for the presentation of results

1.3.3 General terminology

Table 1.3 General terminology

System	A collection of components that carry out a function
Efficiency	This is a simple measure of any system. It can be scientific for example, if the power out of a system is less than the power put in, its percentage efficiency can be determined (P-out/P-in × 100%). This could, for example, be given as say 80%. In a less scientific example, a vehicle using more fuel than normal is said to be inefficient
Noise	Emanations of a sound from a system that is either simply unwanted or is not the normal sound that should be produced
Active	Any system that is in operation all the time (steering for example)
Passive	A system that waits for an event before it is activated (an air bag is a good example)
Short circuit	An electrical conductor is touching something that it should not be touching (usually another conductor of the chassis)
Open circuit	A circuit that is broken (a switched off switch is an open circuit)
High resistance	In relation to electricity this is part of a circuit that has become more difficult for the electricity to get through. In a mechanical system, a partially blocked pipe would have a resistance to the flow of fluid
Worn	This word works better with further additions such as worn to excess, worn out of tolerance or even, worn, but still within tolerance
Quote	To make an estimate of or give exact information on the price of a particular service. A quotation may often be considered to be legally binding
Estimate	A statement of the expected cost of a certain job (e.g. vehicle repairs). An estimate is normally a best guess and is not legally binding
Bad	Not good – and also not descriptive enough really
Dodgy, knackered or @#%&*.	Words often used to describe a system or component, but they mean nothing. Get used to describing things so that misunderstandings are eliminated

1.4 Report writing

1.4.1 Introduction

As technicians you may be called on to produce a report for a customer. If you are involved in research of some kind, it is important to be able to present results in a professional way. The following sections describe the main headings that a report will often need to contain together with an example report based on the performance testing of a vehicle alternator.

Key fact

Setting out results of any test in a standard format is the best way to ensure all the important and required aspects of the test have been covered.

Laying out results in a standard format is the best way to ensure all the important and required aspects of the test have been covered. Keep in mind that the report should convey clearly to another person what has been done. Further, a 'qualified' person should be able to extract enough information to be able to repeat the test – and check your findings. Use clear simple language remembering that in some cases the intended audience may not be as technically competent as you are.

1.4.2 Main headings of a report

The following suggestions for the headings of a professional report will cover most requirements but can, of course, be added to or subtracted from if necessary. After each heading, I have included brief notes on what should be included.

Contents

If the report is more than about f ve pages, a list of contents with page numbers will help the reader f nd his or her way through it.

Introduction

Explain the purpose of what has been done and set the general scene.

Test criteria

Def ne the limits within which the test was carried out. For example, temperature range or speed settings.

Facilities/Resources

State or describe what equipment was used. For example: 'A "Revitup" engine dynamometer, model number C3PO was used for the consumption test'.

Test procedures

Explain here exactly what was done to gain the results. In this part of the report, it is very important not to leave out any details.

Measured results

Present the results in a way that is easy to interpret. A simple table of f gures may be appropriate. If the trend of the results or a comparison is important, a graph may be better. Pictures of results or oscilloscope waveforms may be needed. If necessary a very complex table of results from which you draw out a few key f gures could be presented as an appendix. You should also note the accuracy of any f gures presented (±0.5% for example).

Key fact

Present test results in a way that is easy to interpret.

Analysis of results

This is the part where you should make comment on the results obtained. For example, if, say, a fuel consumption test was carried out on two vehicles, a graph comparing one result to the other may be appropriate. Comments should be added if necessary, such as any anomaly that could have affected the results (change of wind direction for example).

Conclusions/Comments/Observations

Note here any further tests that may be necessary. Conclude that device X does perform better than device Y – if it did. If appropriate, add observations such as how device Y performed better under the set conditions, but under other circumstances the results could have been different. Comment on the method used if necessary.

Forecast

If necessary comment on how the 'item' tested will continue to perform based on the existing data.

Appendices

Detailed pages of results that would 'clog up' the main report or background material such as leaf ets relating to the test equipment.

1.4.3 Example report

An example report is presented here relating to a simple alternator test where its actual output is to be compared to the rated output. Minimal details are included so as just to illustrate the main points.

Introduction

A 'Rotato' 12 V alternator was tested under different temperature conditions to check its maximum output. The manufacturer's specif cations stated that the alternator, when hot, should produce 95 A at 6000 rpm.

Test criteria

Start at room temperature.

Run alternator at 3000 rpm, 30 A output for 10 minutes.

Run alternator at 6000 rpm, maximum output. Check reading every 30 seconds for 10 minutes.

Run alternator at 6000 rpm, maximum output for a further 20 minutes to ensure output reading is stable.

Facilities/Resources

A 'Krypton' test bench model R2D2 was used to drive the alternator. The test bench revcounter was used and a 'Flake' digital meter f tted with a 200 A shunt was used to measure the output. A variable resistance load was employed.

Test procedures

The alternator was run for 10 minutes at 3000 rpm and the load adjusted to cause an output of 30 A. This was to ensure it was at a nominal operating temperature. The normal fan was kept in place during the test.

Speed was then increased to 6000 rpm and the load adjusted to achieve the maximum possible output. The load was further adjusted as required to keep the maximum possible output in case the load resistance changed due to temperature. Measurements were taken every 30 seconds for a period of 10 minutes.

Measured results

Speed held constant at 6000 (±200) rpm

Room temperature (18 °C)

See Table 1.4.

To ensure the alternator output had stabilised it was kept running for a further 20 minutes at full output. It continued to hold at 96 A.

Analysis of results

Figure 1.2 shows the results in graphical format.

Table 1.4 Results

Time (±1 s)	0	30	60	90	120	150	180	210	240	270	300	330	360	390	420	450	480	510	540	570	600
Output (±0.2 A)	101	100	99	99	98	98	98	98	98	98	97	97	96	96	96	96	96	96	96	96	96

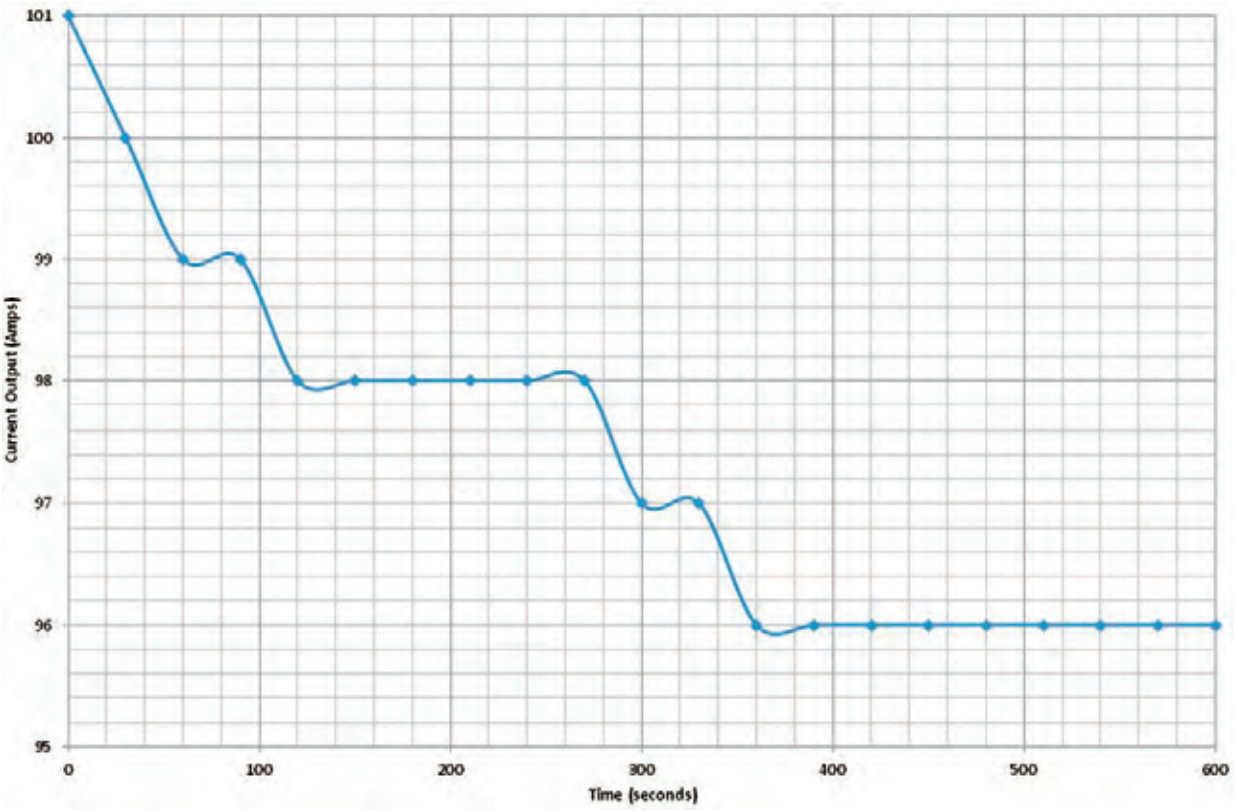


Figure 1.2 Alternator output current over time

Conclusions

The manufacturer's claims were validated. The device exceeded the rated output by 6% at the start of the test and under continuous operation at full load, continued to exceed the rated output by 1%.

The overall duration of this test was 40 minutes, it is possible, however, that the device would increase in temperature and the output may fall further after prolonged operation. Further tests are necessary to check this, for example, under more realistic vehicle operating conditions.

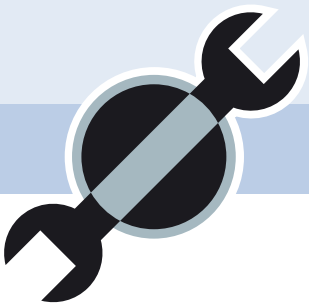
Overall the device performed in excess of its rated output in this test.



(Always sign and date the report)

Tom Denton, March 2012

CHAPTER



Diagnostic techniques

2.1 Introduction

2.1.1 Logic

Diagnostics or faultf nding is a fundamental part of an automotive technician's work. The subject of diagnostics does not relate to individual areas of the vehicle. If your knowledge of a vehicle system is at a suitable level, then you will use the same logical process for diagnosing the fault, whatever the system.

2.1.2 Information

Information and data relating to vehicles are available for carrying out many forms of diagnostic work. The data may come as a book, online or on CD/DVD. This information is vital and will ensure that you f nd the fault – particularly if you have developed the diagnostic skills to go with it. Faultf nding charts and specif c examples are presented in later chapters. The general type of information available is as follows:

- engine diagnostics, testing and tuning;
- servicing, repairs and times;
- fuel and ignition systems;
- auto electrics data;
- component location;
- body repairs, tracking and tyres.

2.1.3 Where to stop?

This is one of the most diff cult skills to learn. It is also one of the most important. The secret is twofold:

- know your own limitations – it is not possible to be good at everything;
- leave systems alone where you could cause more damage or even injury – for example, air bag circuits.

Often with the best of intentions, a person new to diagnostics will not only fail to f nd the fault but also introduce more faults into the system in the process. I would suggest you learn your own strengths and weaknesses; you may be conf dent and good at dealing with mechanical system problems but less so when electronics is involved. Of course you may be just the opposite of this.



Key fact

Know your own limitations.

Advanced Automotive Fault Diagnosis.
© 2012 Tom Denton. Published by Routledge. All rights reserved.

Remember that diagnostic skill is in two parts – the knowledge of the system and the ability to apply diagnostics. If you do not yet fully understand a system, leave it alone until you do.

2.2 Diagnostic process

2.2.1 Six-stage process

A key checklist – the six stages of fault diagnosis – is given in Table 2.1 and Figure 2.1 shows this as a f ow chart.

Here is a very simple example to illustrate the diagnostic process. The reported fault is excessive use of engine oil.

1 Question the customer to f nd out how much oil is being used (is it excessive?).
2 Examine the vehicle for oil leaks and blue smoke from the exhaust. Are there any service bulletins?

Table 2.1 Stages of diagnostics

1. Verify: Is there actually a problem, can you confirm the symptoms
2. Collect: Get further information about the problem, by observation and research
3. Evaluate: Stop and think about the evidence
4. Test: Carry out further tests in a logical sequence
5. Rectify: Fix the problem
6. Check: Make sure all systems now work correctly

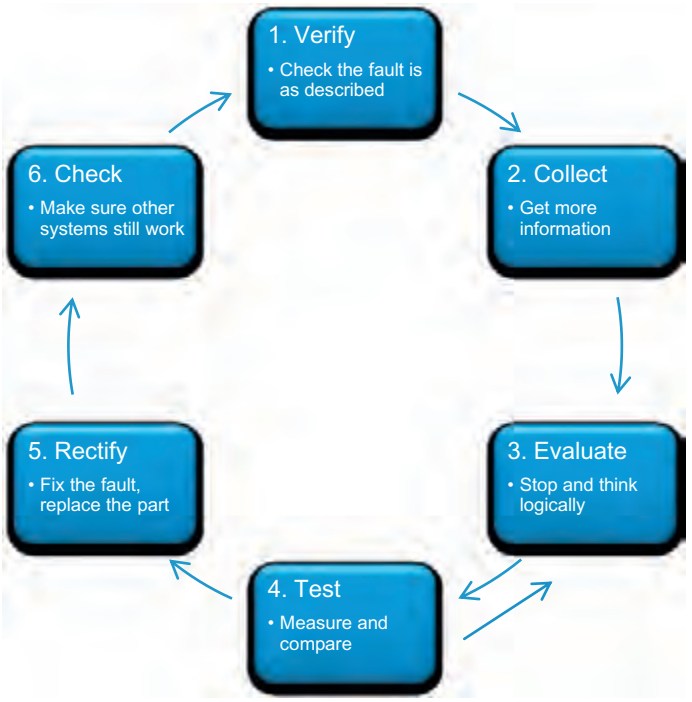


Figure 2.1 Six-stage diagnostic process

3 If leaks are found the engine could still be burning oil but leaks would be a likely cause.
4 A compression test, if the results were acceptable, would indicate a leak to be the most likely fault. Clean down the engine and run for a while. The leak will show up better.
5 Change a gasket or seal, etc.
6 Run through an inspection of the vehicle systems particularly associated with the engine. Double-check that the fault has been rectif ed and that you have not caused any further problems.

The six-stage diagnostic process will be used extensively to illustrate how a logical process can be applied to any situation.

Key fact

The six-stage diagnostic process is recommended but there are others that are similar – the important thing is to follow any 'process' logically:

1. Verify
2. Collect
3. Evaluate
4. Test
5. Rectify
6. Check.

2.2.2 The art of diagnostics

The knowledge needed for accurate diagnostics is in two parts:

1 understanding of the system in which the problem exists;
2 having the ability to apply a logical diagnostic routine.

The knowledge requirement and use of diagnostic skills can be illustrated with a very simple example:

After connecting a hosepipe and turning on the tap, no water comes out of the end. Your knowledge of this system tells you that water should come out providing the tap is on, because the pressure from a tap pushes water through the pipe, and so on. This is where your diagnostic skills become essential. The following stages are now required:

Safety f rst

Don't point any pipes at your eyes.

1 Conf rm that no water is coming out by looking down the end of the pipe.
2 Check if water comes out of the other taps, or did it come out of this tap before you connected the hose?
3 Consider what this information tells you; for example, if the answer is 'Yes' the hose must be blocked or kinked.
4 Walk the length of the pipe looking for a kink.
5 Straighten out the hose.
6 Check that water now comes out and that no other problems have been created.

Much simplif ed I accept, but the procedure you have just followed made the hose work and it is also guaranteed to f nd a fault in any system. It is easy to see how it works in connection with a hosepipe and I'm sure anybody could have found that fault (well most people anyway).

The higher skill is to be able to apply the same logical routine to more complex situations. The routine (Table 2.1) is also represented by Figure 2.1. The loop will continue until the fault is located.

I will now explain each of these steps further in relation to a more realistic automotive workshop situation – not that getting the hose to work is not important! Often electrical faults are considered to be the most diff cult to diagnose – but this is not true. I will use a vehicle cooling system fault as an example here, but electrical systems will be covered in detail in later chapters. Remember that the diagnostic procedure can be applied to any problem – mechanical, electrical or even medical.

However, let us assume that the reported fault with the vehicle is overheating. As is quite common in many workshop situations that's all the information we have to start with. Now work through the six stages:

- Stage 1 – Take a quick look to check for obvious problems such as leaks, broken drive belts or lack of coolant. Run the vehicle and conf rm that the fault exists. It could be the temperature gauge, for example.
- Stage 2 – Is the driver available to give more information? For example, does the engine overheat all the time or just when working hard? Check records, if available, of previous work done to the vehicle.
- Stage 3 – Consider what you now know. Does this allow you to narrow down what the cause of the fault could be? For example, if the vehicle overheats all the time and it had recently had a new cylinder head gasket f tted, would you be suspicious about this? Do not let two and two make f ve, but do let it act as a pointer. Remember that in the science of logical diagnostics, two and two always makes four. However, until you know this for certain then play the best odds to narrow down the fault.
- Stage 4 – The further tests carried out would now be directed by your thinking at stage 3. You do not yet know if the fault is a leaking head gasket, the thermostat stuck closed or some other problem. Playing the odds, a cooling system pressure test would probably be the next test. If the pressure increases when the engine is running, then it is likely to be a head gasket or similar problem. If no pressure increase is noted, then move on to the next test and so on. After each test go back to stage 3 and evaluate what you know, not what you don't know.
- Stage 5 – Let us assume the problem was a thermostat stuck closed – replace it and top up the coolant, etc.
- Stage 6 – Check that the system is now working. Also check that you have not caused any further problems such as leaks or loose wires.

This example is simplif ed a little, but like the hosepipe problem it is the sequence that matters, particularly the 'stop and think' at stage 3. It is often possible to go directly to the cause of the fault at this stage, providing that you have an adequate knowledge of how the system works.

2.2.3 Concern, cause, correction

The three Cs, as concern, cause, correction are sometimes described, is another reminder that following a process for automotive repairs and diagnostics is essential.

It is in a way a simplif ed version of our six-stage process as shown in Table 2.2.

Table 2.2 Repair and diagnostic processes

Six-stage process	CCC
Verify	Concern
Collect Evaluate Test	Cause
Rectify Check	Correction

Table 2.3 is a further example where extra suggestions have been added as a reminder of how important it is to collect further information. It is also recommended that this information and process is included on the jobsheet so the customer is kept informed. Most customer complaints come about because of poor work or poor communication – this may be acceptable in some poor quality establishments but not in any that you and I are involved in – be professional and you will be treated like one (lecture over, sorry).

So, while the concern, cause, correction sequence is quite simple, it is very effective as a means of communication as well as a diagnosis and repair process. An example jobcard/jobsheet is available for download from www.automotive-technology.co.uk that includes the three Cs. It is ideal as a training aid as well as for real use.

Key fact

Most customer complaints are as a result of poor work or poor communication.

2.2.4 Root cause analysis

The phrase 'root cause analysis' (RCA) is used to describe a range of problem-solving methods aimed at identifying the root causes of problems or events. I have included this short section because it helps to reinforce the importance of keeping an open mind when diagnosing faults, and again, stresses the need to

Table 2.3 CCC process

Process outline	Example situation	Notes
Customer Concern:	Battery seems to be discharged and will sometimes not start the car. It seems to be worse when the headlights are used	This should set you thinking that the cause is probably a faulty battery, a charging system fault, a parasitic discharge or a starter motor problem (the symptoms would suggest a charging fault is most likely but keep an open mind)
Vehicle service history information:	Car is five years old, has done 95 000 miles but has a good service history. A new battery was fitted one year ago and the cam belt was replaced two years ago	Battery probably ok and drive belt adjustment likely to be correct (still suspicious of a charging fault)
Related technical service bulletins:	New camshaft drive belt should be fitted every 50 000 miles	Not connected but it would be good to recommend that the belt was changed at this time
Diagnostic procedures performed:	Battery voltage and discharge test – ok Drive belt tension – ok (but a bit worn) Alternator charging voltage – 13 V Checked charging circuit for volt drop – ok	14 V is the expected charging voltage on most systems
Cause:	Alternator not producing correct voltage	An auto electrician may be able to repair the alternator but for warranty reasons a new or reconditioned one is often best (particularly at this mileage)
Correction:	Reconditioned alternator and new drive belt fitted and checked – charging now ok at 14 V	Note how by thinking about this process we had almost diagnosed the problem before doing any tests, also note that following this process will make us confident that we have carried out the correct repair first time. The customer will appreciate this – and will come back again

Definition

RCA: Root cause analysis.

work in a logical and structured way. The root cause of a problem is not always obvious; an example will help to illustrate this:

Let us assume the symptom was that one rear light on a car did not work. Using the six-stage process, a connector block was replaced as it had an open circuit fault. The light now works ok but what was missed was that a small leak from the rear screen washer pipe dripped on the connector when the washer was operated. This was the root cause.

The practice of RCA is based, quite rightly, on the belief that problems are best solved by attempting to address, correct or eliminate the root causes, as opposed to just addressing the faults causing observable symptoms. By dealing with root causes, it is more likely that problems will not reoccur. RCA is best considered to be an iterative process because complete prevention of recurrence by one corrective action is not always realistic.

Root causes of a problem can be in many different parts of a process. This is sometimes represented by a 'f shbone' diagram. Two examples are presented as Figures 2.2 and 2.3. These show how any one cause on any one branch (or rib) can result in a problem at the end of a more complex process.

RCA is usually used as a reactive method of identifying causes, revealing problems and solving them and it is done after an event has occurred. However,

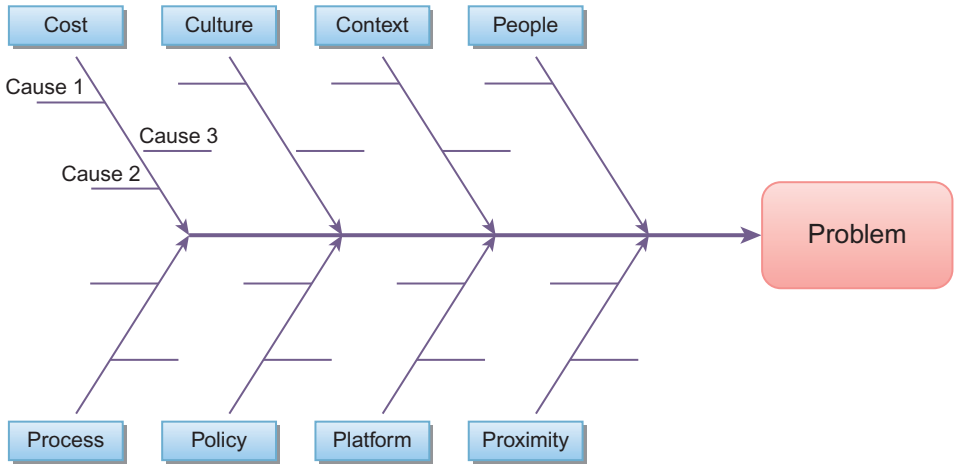


Figure 2.2 Fishbone diagram showing possible root causes of a problem in software development

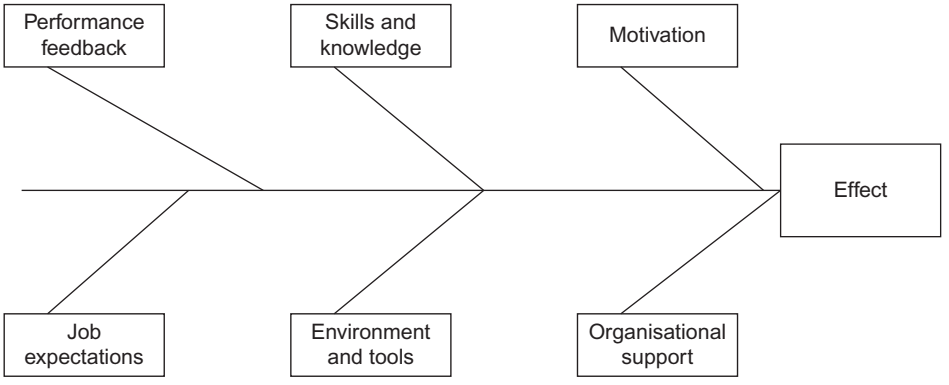


Figure 2.3 Fishbone diagram that could be used to look at diagnostic processes

RCA can be a useful proactive technique because, in some situations, it can be used to forecast or predict probable events.

RCA is not a single def ned methodology. There are a number of different ways of doing the analysis. However, several very broadly def ned methods can be identif ed:

- Safety-based RCA descends from the f elds of accident analysis and occupational safety and health.
- Production-based RCA has its origins in the f eld of quality control for industrial manufacturing.
- Process-based RCA is similar to production-based RCA, but has been expanded to include business processes.
- Failure-based RCA comes from the practice of failure analysis used in engineering and maintenance.

The following list is a much simplif ed representation of a failure-based RCA process. Note that the key steps are numbers 3 and 4. This is because they direct the corrective action at the true root cause of the problem.

1. Def ne the problem.
2. Gather data and evidence.
3. Identify the causes and root causes.
4. Identify corrective action(s).
5. Implement the root cause correction(s).
6. Ensure effectiveness (Figure 2.4).

As an observant reader, you will also note that these steps are very similar to our six-stage faultf nding process.

Key fact

RCA directs the corrective action at the true root cause of the problem.

2.2.5 Summary

I have introduced the six-stage process of diagnostics, not so that it should always be used as a checklist but to illustrate how important it is to follow a

Key fact

Six-stage process:

1. Verify
2. Collect
3. Evaluate
4. Test
5. Rectify
6. Check.

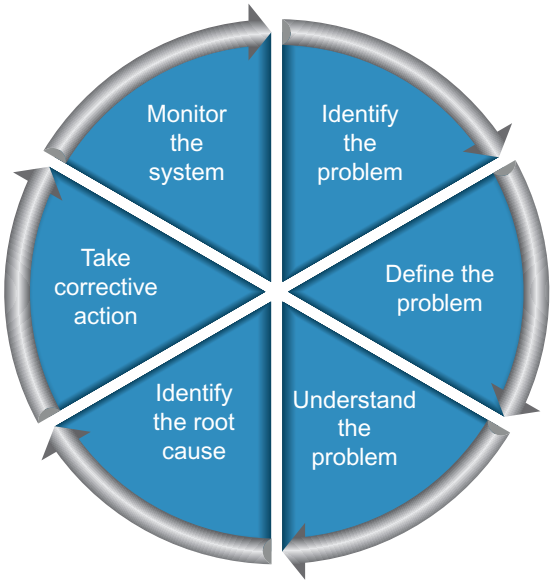


Figure 2.4 RCA process

Def nition

'Logic is the beginning of wisdom not the end'. (Spock to Mr Valeris, *Star Trek II*).

process. Much more detail will be given later, in particular about stages 3 and 4. The purpose of this set process is to ensure that 'we' work in a set, logical way.

2.3 Diagnostics on paper

2.3.1 Introduction

Key fact

Stop and think before pulling the vehicle to pieces.

This section is again a way of changing how you approach problems on a vehicle. The key message is that if you stop and think before 'pulling the vehicle to pieces', it will often save a great deal of time. In other words, some of the diagnostic work can be done 'on paper' before we start on the vehicle. To illustrate this, the next section lists symptoms for three separate faults on a car and for each of these symptoms, three possible faults.

2.3.2 Examples

All the faults are possible in the following example, but in each case see which you think is the 'most likely' option (Table 2.4).

The most likely fault for example A is number 3. It is possible that all the lights have blown but unlikely. It could not be the auxiliary relay because this would affect other systems.

For example B, the best answer would be number 2. It is possible that the pump pressure is low but this would be more likely to affect operation under other conditions. A loose wire on the engine speed sensor could cause the engine to stall but it would almost certainly cause misf re under other conditions.

The symptoms in example C would suggest answer 1. The short circuit suggested as answer 3 would be more likely to cause lights and others to stay on rather than not work, equally the chance of a short between these two circuits is remote if not impossible. If the lighting fusible link were blown then none of the lights would operate.

The technique suggested here relates to stages 1–3 of the 'the six stages of fault diagnosis' process. By applying a little thought before even taking a screwdriver to the car, a lot of time can be saved. If the problems suggested in the previous table were real we would at least now be able to start looking in the right area for the fault.

Table 2.4 Example faults

Symptoms	Possible faults
A: The brake/stoplights are reported as not operating. On checking it is confirmed that neither of the two bulbs or the row of high-mounted LEDs are operating as the pedal is pressed. All other systems work correctly	1. Two bulbs and 12 LEDs blown 2. Auxiliary systems relay open circuit 3. Brake light switch not closing
B: An engine fitted with full management system tends to stall when running slowly. It runs well under all other conditions and the reported symptom is found to be intermittent	1. Fuel pump output pressure low 2. Idle control valve sticking 3. Engine speed sensor wire loose
C: The off side dip beam headlight not operating. This is confirmed on examination and also noted that the off side tail lights do not work	1. Two bulbs blown 2. Main lighting fusible link blown 3. Short circuit between off side tail and dip beam lights

2.3.3 How long is a piece of string?

Yes I know, twice the distance from the middle to one end. What I am really getting at here though is the issue about what is a valid reading or measurement and what is not – when compared to data. For example, if the 'data source' says the resistance of the component should be between 60 and 90Ω, what do you do when the measured value is 55Ω? If the measured value was 0Ω or 1000Ω then the answer is easy – the component is faulty. However, when the value is very close you have to make a decision. In this case (55Ω) it is very likely that the component is serviceable.

The decision over this type of issue is diff cult and must, in many cases, be based on experience. As a general guide, however, I would suggest that if the reading is in the right 'order of magnitude', then the component has a good chance of being OK. By this I mean that if the value falls within the correct range of 1s, 10s, 100s or 1000s, etc, then it is probably good.

Do notice that I have ensured that words or phrases such as 'probably', 'good chance' and 'very likely' have been used here. This is not just to make sure I have a get out clause; it is also to illustrate that diagnostic work can involve 'playing the best odds' – as long as this is within a logical process.

Def nition

Order of magnitude:

- A degree in a continuum of size or quantity;
- A number assigned to the ratio of two quantities;
- Two quantities are of the same order of magnitude if one is less than 10 times as large as the other;
- The number of magnitudes that the quantities differ is specified to within a power of 10.

2.4 Mechanical diagnostic techniques

2.4.1 Check the obvious f rst

Start all hands-on diagnostic routines with 'hand and eye checks'. In other words, look over the vehicle for obvious faults. For example, if automatic transmission f uid is leaking on to the f oor then put this right before carrying out complicated stall tests. Here are some further suggestions that will at some point save you a lot of time.

- If the engine is blowing blue smoke out of the exhaust – consider the worth of tracing the cause of a tapping noise in the engine.
- When an engine will not start – check that there is fuel in the tank (Figure 2.5).

Key fact

All diagnostic routines should include 'hand and eye checks'.

2.4.2 Noise, vibration and harshness

Noise, vibration and harshness (NVH) concerns have become more important as drivers have become more sensitive to these issues. Drivers have higher expectations of comfort levels. NVH issues are more noticeable due to reduced engine noise and better insulation in general. The main areas of the vehicle that produce NVH are:

- tyres;
- engine accessories;
- suspension;
- driveline.

It is necessary to isolate the NVH into its specif c area(s) to allow more detailed diagnosis. A road test, as outlined later, is often the best method.

The f ve most common sources of non-axle noise are exhaust, tyres, roof racks, trim and mouldings, and transmission. Ensure that none of the following

Def nition

NVH: Noise, vibration and harshness.

Key fact

The f ve most common sources of non-axle noise are exhaust, tyres, roof racks, trim and mouldings, and transmission.

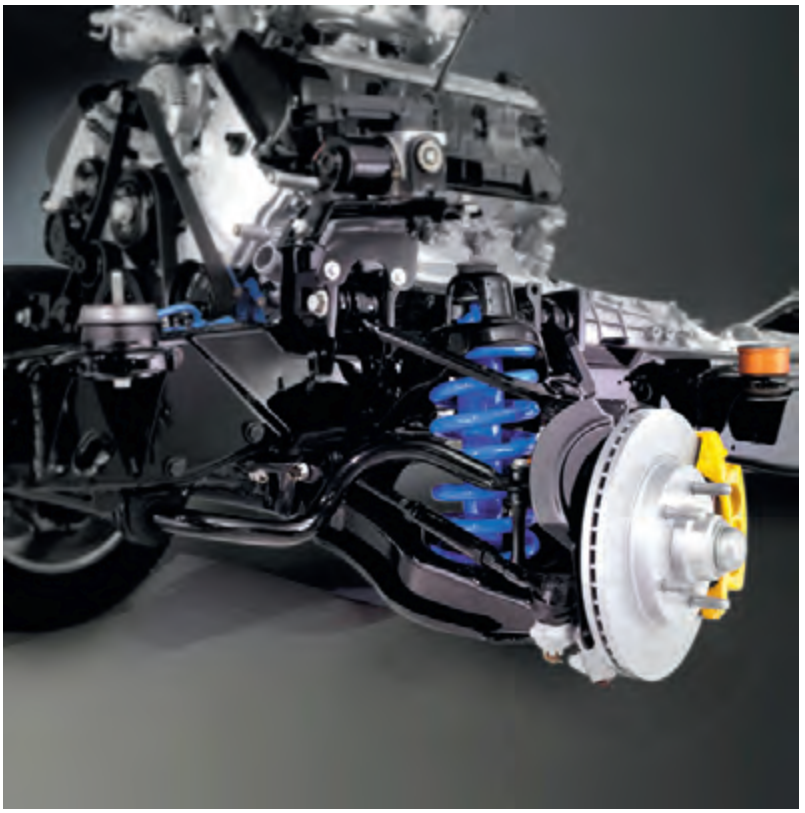


Figure 2.5 Mechanical systems

conditions is the cause of the noise before proceeding with a driveline strip down and diagnosis.

1. In certain conditions, the pitch of the exhaust may sound like gear noise or under other conditions like a wheel bearing rumble.
2. Tyres can produce a high-pitched tread whine or roar, similar to gear noise. This is particularly the case for non-standard tyres.
3. Trim and mouldings can cause whistling or whining noises.
4. Clunk may occur when the throttle is applied or released due to backlash somewhere in the driveline.
5. Bearing rumble sounds like marbles being tumbled.

2.4.3 Noise conditions

Noise is very diff cult to describe. However, the following are useful terms and are accompanied by suggestions as to when they are most likely to occur.

- Gear noise is typically a howling or whining due to gear damage or incorrect bearing preload. It can occur at various speeds and driving conditions or it can be continuous.
- 'Chuckle' is a rattling noise that sounds like a stick held against the spokes of a spinning bicycle wheel. It usually occurs while decelerating.
- Knock is very similar to chuckle though it may be louder and occurs on acceleration or deceleration.

Check and rule out tyres, exhaust and trim items before any disassembly to diagnose and correct gear noise.

2.4.4 Vibration conditions

Clicking, popping or grinding noises may be noticeable at low speeds and be caused by the following:

- inner or outer CV joints worn (often due to lack of lubrication, so check for split gaiters);
- loose drive shaft;
- another component contacting a drive shaft;
- damaged or incorrectly installed wheel bearing, brake or suspension component.

The following may cause vibration at normal road speeds:

- out-of-balance wheels;
- out-of-round tyres.

The following may cause shudder or vibration during acceleration:

- damaged powertrain/drivetrain mounts;
- excessively worn or damaged out-board or in-board CV joints.

The cause of noise can often be traced by f rst looking for leaks. A dry bearing or joint will produce signif cant noise.

1 Inspect the CV joint gaiters (boots) for cracks, tears or splits.
2 Inspect the underbody for any indication of grease splatter near the front wheel half shaft joint boots.
3 Inspect the in-board CV joint stub shaft bearing housing seal for leakage at the bearing housing.
4 Check the torque on the front axle wheel hub retainer.

2.4.5 Road test

A vehicle will produce a certain amount of noise. Some noise is acceptable and may be audible at certain speeds or under various driving conditions such as on a new road.

Carry out a thorough visual inspection of the vehicle before carrying out the road test. Keep in mind anything that is unusual. A key point is to not repair or adjust anything until the road test is carried out. Of course this does not apply if the condition could be dangerous or the vehicle will not start.

Establish a route that will be used for all diagnostic road tests. This allows you to get to know what is normal and what is not. The roads selected should have sections that are reasonably smooth, level and free of undulations as well as lesser quality sections needed to diagnose faults that only occur under particular conditions. A road that allows driving over a range of speeds is best. Gravel, dirt or bumpy roads are unsuitable because of the additional noise they produce.

If a customer's concern is a noise or vibration on a particular road and only on a particular road, the source of the concern may be the road surface. Test the vehicle on the same type of road. Make a visual inspection as part of the preliminary diagnosis routine prior to the road test; note anything that does not look right. For example,

1 tyre pressures, but do not adjust them yet;
2 leaking f uids;
3 loose nuts and bolts;

Key fact

Establish a standard route that will be used for all diagnostic road tests so you know what to expect.

4 bright spots where components may be rubbing against each other;
5 check the luggage compartment for unusual loads.

Road test the vehicle and def ne the condition by reproducing it several times during the road test. During the road test recreate the following conditions:

1 Normal driving speeds of 20–80 km/h (15–50 mph) with light acceleration – a moaning noise may be heard and possibly a vibration is felt in the front f oor pan. It may get worse at a certain engine speed or load.
2 Acceleration/deceleration with slow acceleration and deceleration – a shake is sometimes noticed through the steering wheel seats, front f oor pan, front door trim panels, etc.
3 High speed – a vibration may be felt in the front f oor pan or seats with no visible shake, but with an accompanying sound or rumble, buzz, hum, drone or booming noise. Coast with the clutch pedal down or gear lever in neutral and engine idling. If vibration is still evident, it may be related to wheels, tyres, front brake discs, wheel hubs or wheel bearings.
4 Engine rpm sensitive – a vibration may be felt whenever the engine reaches a particular speed. It may disappear in neutral coasts. Operating the engine at the problem speed while the vehicle is stationary can duplicate the vibration. It can be caused by any component, from the accessory drive belt to the clutch or torque converter, which turns at engine speed when the vehicle is stopped.
5 Noise and vibration while turning – clicking, popping or grinding noises may be due to the following: damaged CV joint; loose front wheel half shaft joint boot clamps; another component contacting the half shaft; worn, damaged or incorrectly installed wheel bearing; damaged powertrain/drivetrain mounts.

After a road test, it is often useful to do a similar test on a hoist or lift. When carrying out a ‘shake and vibration’ diagnosis or ‘engine accessory vibration’ diagnosis on a lift, observe the following precautions:

- If only one drive wheel is allowed to rotate, speed must be limited to 55 km/h (35 mph) indicated on the speedometer. This is because the actual wheel speed will be twice that indicated on the speedometer.
- The suspension should not be allowed to hang free. If a CV joint were run at a high angle, extra vibration as well as damage to the seals and joints could occur.

Support the front suspension lower arm as far out-board as possible. This will ensure that the vehicle is at its correct ride height. The procedure is outlined by the following steps:

1 Raise and support the vehicle.
2 Explore the speed range of interest using the road test checks as previously discussed.
3 Carry out a coast down (overrun) in neutral. If the vehicle is free of vibration when operating at a steady indicated speed and behaves very differently in drive and coast, a transmission concern is likely.

A test on the lift may produce different vibrations and noises than a road test because of the effect of the lift. It is not unusual to f nd a vibration on the lift that was not noticed during the road test. If the condition found on the road can be duplicated on the lift, carrying out experiments on the lift may save a great deal of time.

2.4.6 Engine noises

How do you tell a constant tapping from a rattle? Worse still, how do you describe a noise in a book? I’ll do my best. Try the following table as a non-def nitive guide to the source or cause of engine or engine ancillary noises (Table 2.5).

Table 2.5 Noise diagnostics

Noise description	Possible source
Tap	Valve clearances out of adjustment, cam followers or cam lobes worn
Rattle	A loose component, broken piston ring or component
Light knock	Small-end bearings worn, cam or cam follower
Deep knock or thud	Big-end bearings worn
Rumble	Main bearings worn
Slap	Worn pistons or bores
Vibration	Loose or out-of-balance components
Clatter	Broken rocker shaft or broken piston rings
Hiss	Leak from inlet or exhaust manifolds or connections
Roar	Air intake noise, air filter missing, exhaust blowing or a seized viscous fan drive
Clunk	Loose flywheel, worn thrust bearings or a loose front pulley/damper
Whine	Power steering pump or alternator bearing
Shriek	Dry bearing in an ancillary component
Squeal	Slipping drive belt

Table 2.6 Engine noises

Sources of engine noise	Possible cause	Required action
Misfiring/backfiring	Fuel in tank has wrong octane/cetane number or is wrong type of fuel Ignition system faulty Engine temperature too high Carbon deposits in the combustion chamber start to glow and cause misfiring Timing incorrect, which causes misfiring in the intake/exhaust system	Determine which type of fuel was last put in the tank Check the ignition system Check the engine cooling system Remove the carbon deposits by using fuel additives and driving the vehicle carefully Check the timing
Valve train faulty	Valve clearance too large due to faulty bucket tappets or incorrect adjustment of valve clearance Valve timing incorrectly adjusted valves and pistons are touching Timing belt broken or damaged	Adjust valve clearance if possible and renew faulty bucket tappets – check cam condition Check the valve timing and adjust if necessary Check timing belt and check pistons and valves for damage – renew any faulty parts
Engine components faulty	Pistons Piston rings Cylinder head gasket Big-end and/or main bearing journals	Disassemble the engine and check components
Ancillary components	Engine components or ancillary components loose or broken	Check that all components are secure, tighten/adjust as required. Renew if broken

2.4.7 Sources of engine noise

The above table is a further guide to engine noise. Possible causes are listed together with the necessary repair or further diagnosis action as appropriate (Table 2.6).

2.5 Electrical diagnostic techniques

2.5.1 Check the obvious f rst

Start all hands-on diagnostic routines with ‘hand and eye checks’. In other words, look over the vehicle for obvious faults. For example, if the battery terminals are loose or corroded then put this right before carrying out complicated voltage readings. Here are some further suggestions that will at some point save you a lot of time.

- A misf re may be caused by a loose plug lead – it is easier to look for this than interpret the ignition waveforms on a scope.
- If the ABS warning light stays on – look to see if the wheel speed sensor(s) are covered in mud or oil (Figure 2.6).

Key fact

Start all hands-on diagnostic routines with ‘hand and eye checks’.

2.5.2 Test lights and analogue meters – warning

A test lamp is ideal for tracing faults in say a lighting circuit because it will cause a current to f ow, which tests out high-resistance connections. However, it is this same property that will damage delicate electronic circuits – so don’t use it for any circuit that contains an electronic control unit (ECU).

Even an analogue voltmeter can cause enough current to f ow to at best give you a false reading and at worst damage an ECU – so do not use it.

A digital multimeter is ideal for all forms of testing, most have an internal resistance in excess of 10 MΩ, which means that the current they draw is almost insignif cant. An LED test lamp or a logic probe is also acceptable.

Safety f rst

A test lamp will cause a current to f ow, which can damage delicate electronic circuits.

Key fact

A digital multimeter is ideal for all forms of electrical testing.

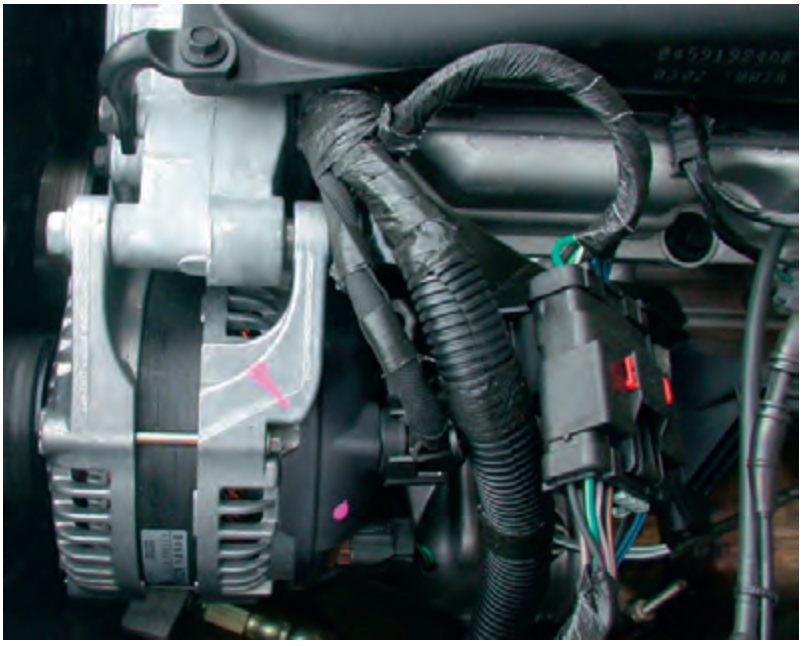


Figure 2.6 Electrical system

2.5.3 Generic electrical testing procedure

The following procedure is very generic but with little adaptation can be applied to any electrical system. Refer to manufacturer's recommendations if in any doubt. The process of checking any system circuit is represented by Figure 2.7.

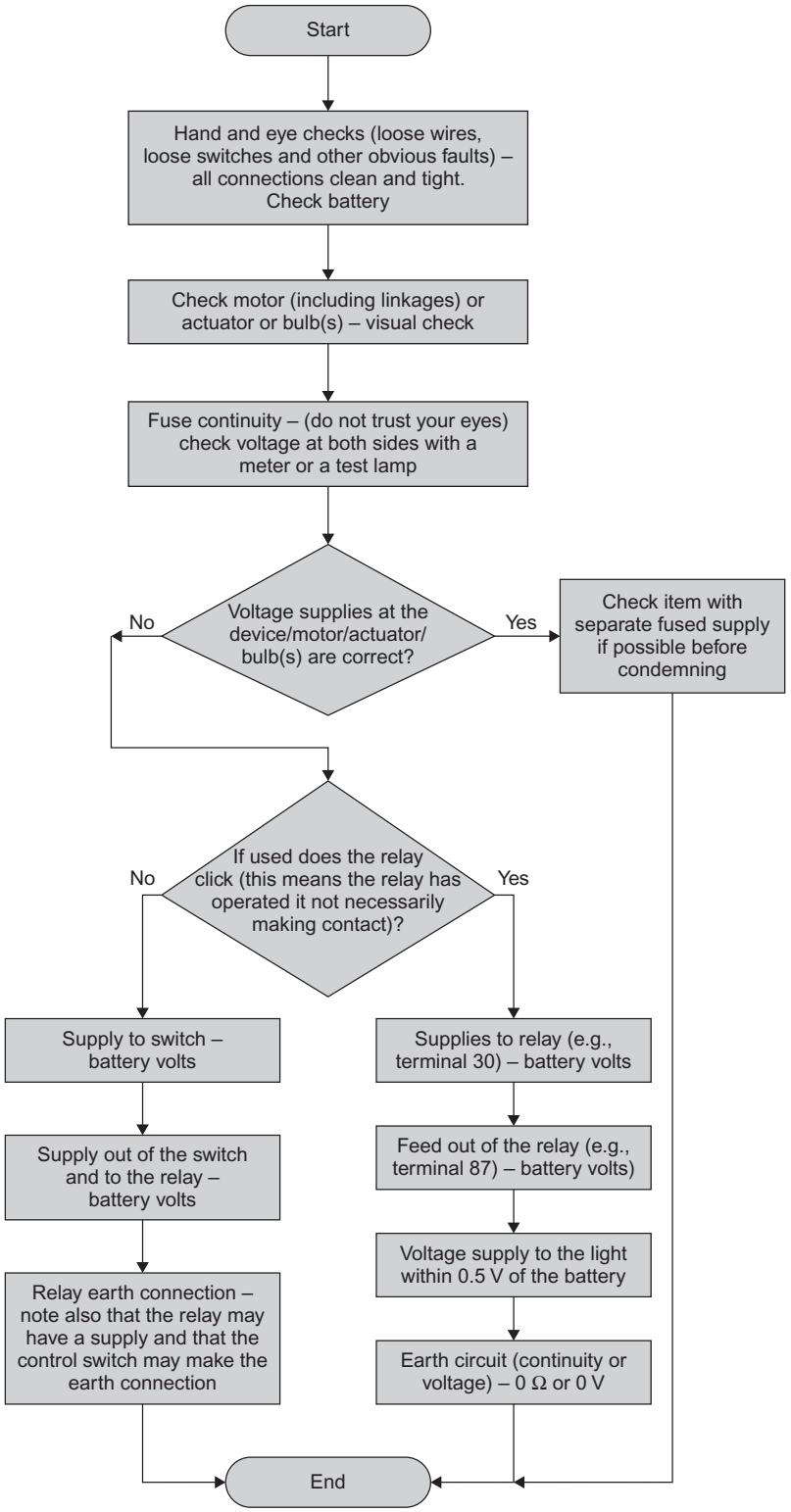


Figure 2.7 Generic electrical diagnostics chart

2.5.4 Volt drop testing

Volt drop is a term used to describe the difference between two points in a circuit. In this way we can talk about a voltage drop across a battery (normally about 12.6 V) or the voltage drop across a closed switch (ideally 0 V but may be 0.1 or 0.2 V).

The f rst secret to volt drop testing is to remember a basic rule about a series electrical circuit:

'The sum of all volt drops around a circuit always add up to the supply'.

Key fact

The sum of all volt drops around a circuit always add up to the supply

The second secret is to ensure the circuit is switched on and operating – or at least the circuit should be 'trying to operate'.

In Figure 2.8 this means that, if the circuit is operating correctly, $V_1 + V_2 + V_3 = V_s$. When electrical testing therefore, and if the battery voltage is measured as say 12 V, a reading of less than 12 V at V_2 would indicate a volt drop between the terminals of V_1 and/or V_3. Likewise the correct operation of the switch, that is, it closes and makes a good connection, would be conf rmed by a very low reading on V_1.

What is often described as a 'bad earth' (when what is meant is a high resistance to earth) could equally be determined by the reading on V_3. To further narrow the cause of a volt drop down, simply measure across a smaller area. The voltmeter V_4, for example, would only assess the condition of the switch contacts.

2.5.5 Testing for short circuits to earth

This fault will normally blow a fuse – or burn out the wiring completely. To trace a short circuit is very different to looking for a high-resistance connection or an open circuit. The volt drop testing above will trace an open circuit or a high-resistance connection.

My preferred method of tracing a short, after looking for the obvious signs of trapped wires, is to connect a bulb or test lamp across the blown fuse and switch on the circuit. The bulb will light because on one side it is connected to the supply for the fuse and on the other side it is connected to earth via the short circuit fault.

Now disconnect small sections of the circuit one at a time until the test lamp goes out. This will indicate the particular circuit section that has shorted out.

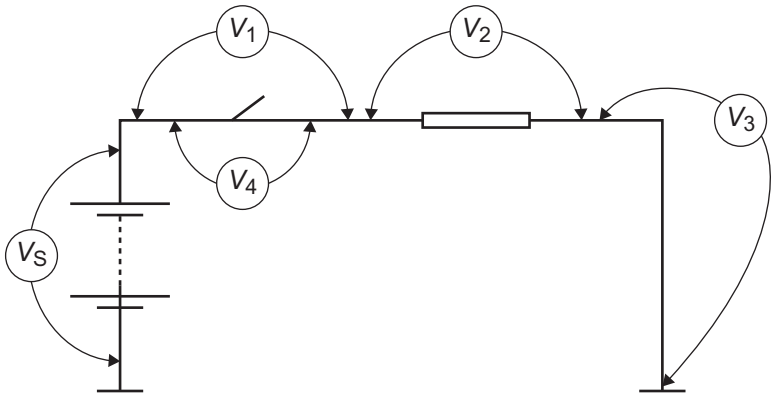


Figure 2.8 Volt drop testing

2.5.6 On and off load tests

On load means that a circuit is drawing a current; off load means it is not. One example where this may be an issue is when testing a starter circuit. Battery voltage may be 12 V (well 12.6 V) off load, but may be as low as 9 V when on load (cranking a cold engine perhaps).

A second example is the supply voltage to the positive terminal of an ignition coil via a high-resistance connection (corroded switch terminal for example). With the ignition on and the vehicle not running, the reading will almost certainly be battery voltage because the ignition ECU switches off the primary circuit and no volt drop will show up. However, if the circuit were switched on (with a fused jumper lead if necessary) a lower reading would result showing up the fault.

2.5.7 Black box technique

The technique outlined here is known as 'black box faultf nding'. This is an excellent technique and can be applied to many vehicle systems from engine management and ABS to cruise control and instrumentation.

As most systems now revolve around an ECU, the ECU is considered to be a 'black box'; in other words, we know what it should do but the exact details of how it does it are less important.

Key fact

Most vehicle systems involve an ECU.

Figure 2.9 shows a block diagram that could be used to represent any number of automobile electrical or electronic systems. In reality the arrows from the 'inputs' to the ECU and from the ECU to the 'outputs' are wires. Treating the ECU as a 'black box' allows us to ignore its complexity. The theory is that if all the sensors and associated wiring to the 'black box' are OK, all the output actuators and their wiring are OK and the supply/earth (ground) connections are OK, then the fault must be the 'black box'. Most ECUs are very reliable however and it is far more likely that the fault will be found in the inputs or outputs.

Normal faultf nding or testing techniques can be applied to the sensors and actuators. For example, if an ABS system uses four inductive-type wheel speed sensors, then an easy test is to measure their resistance. Even if the correct value were not known, it would be very unlikely for all four to be wrong at the same time so a comparison can be made. If the same resistance reading is obtained on the end of the sensor wires at the ECU then almost all of the 'inputs' have been tested with just a few ohmmeter readings.

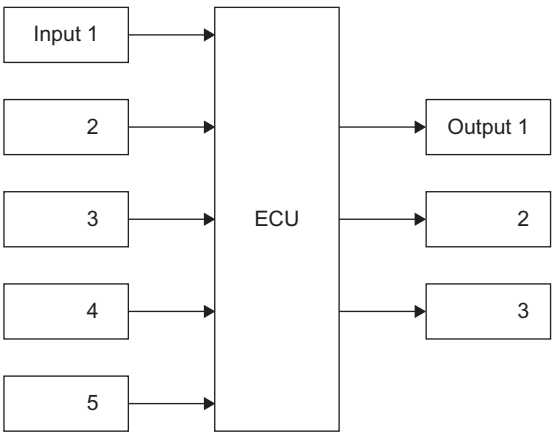


Figure 2.9 System block diagram

Key fact

If the resistance of all similar items connected to an ECU is the same, then it is reasonable to assume the figure is almost certainly correct.

The same technique will often work with 'outputs'. If the resistance of all the operating windings in say a hydraulic modulator were the same, then it would be reasonable to assume the figure was correct.

Sometimes, however, it is almost an advantage not to know the manufacturer's recommended readings. If the 'book' says the value should be between 800 and 900 Ω, what do you do when your ohmmeter reads 905 Ω? Answers on a postcard please… (or see Section 2.3.3).

Finally, don't forget that no matter how complex the electronics in an ECU, they will not work without a good power supply and an earth.

2.5.8 Sensor to ECU method

This technique is simple but very useful. Figure 2.10 shows a resistance test being carried out on a component. Ω_1 is a direct measure of its resistance, whereas Ω_2 includes the condition of the circuit. If the second reading is the same as the first then the circuit must be in good order.

Warning: The circuit supply must always be off when carrying out ohmmeter tests.

2.5.9 Flight recorder tests

It is said that the best place to sit in an aeroplane is on the black box flight recorder. Personally, I would prefer to be in 'first class'! Also – apart from the black box usually being painted bright orange so it can be found after a crash – my reason for mentioning it is to consider how the flight recorder principle can be applied to automotive diagnostics.

Key fact

Most digital oscilloscopes have flight record facilities.

Most digital oscilloscopes have flight record facilities. This means that they will save the signal from any probe connection in memory for later playback. The time duration will vary depending on the available memory and the sample speed but this is a very useful feature.

As an example, consider an engine with an intermittent misfire that only occurs under load. If a connection is made to the suspected component (coil HT output

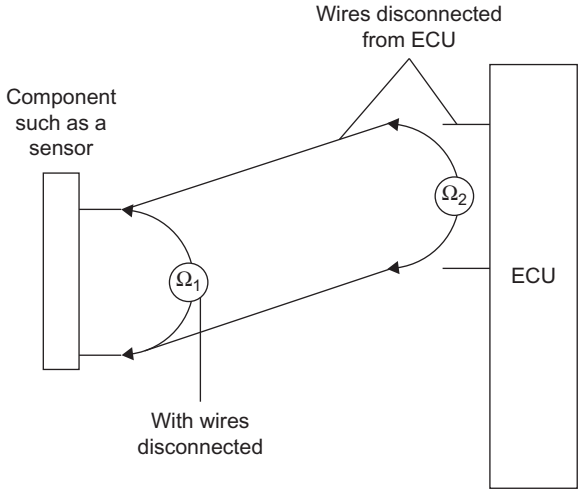


Figure 2.10 Ohmmeter testing

for example), and the vehicle road tested, the waveforms produced can be examined afterwards.

Many engine (and other system) ECUs have built-in f ight recorders in the form of self-diagnostic circuits. If a wire breaks loose causing a misf re but then reconnects, the faulty circuit will be 'remembered' by the ECU.

2.5.10 Faultf nding by luck – or is it logic?

Actually, what this section considers is the benef t of playing the odds which, while sometimes you get lucky, is still a logical process.

If four electric windows stopped working at the same time, it would be very unlikely that all four motors had burnt out. On the other hand if just one electric window stopped working, then it may be reasonable to suspect the motor. It is this type of reasoning that is necessary during faultf nding. However, be warned that it is theoretically possible for four motors to apparently burn out all at the same time.

Using this 'playing the odds' technique can save time when tracing a fault in a vehicle system. For example, if both stop lights do not work and everything else on the vehicle was OK, I would suspect the switch (stages 1–3 of the six-stage process). At this stage though, the fault could be anywhere – even two or three blown bulbs. Nonetheless a quick test at the switch with a voltmeter would prove the point. Now, let's assume the switch is OK and it produces an output when the brake pedal is pushed down. Testing the length of wire from the front to the back of the vehicle further illustrates how 'luck' comes into play.

Figure 2.11 represents the main supply wire from the brake switch to the point where the wire 'divides' to each individual stop light (the odds say the fault must be in this wire). For the purpose of this illustration we will assume the open circuit is just before point 'I'. The procedure continues in one of the two following ways:

One

- Guess that the fault is in the f rst half and test at point F.
- We were wrong. Guess that the fault is in the f rst half of the second half and test at point I.
- We were right. Check at H and we have the fault … In only 3 tests

Two

- Test from A to K in a logical sequence of tests.

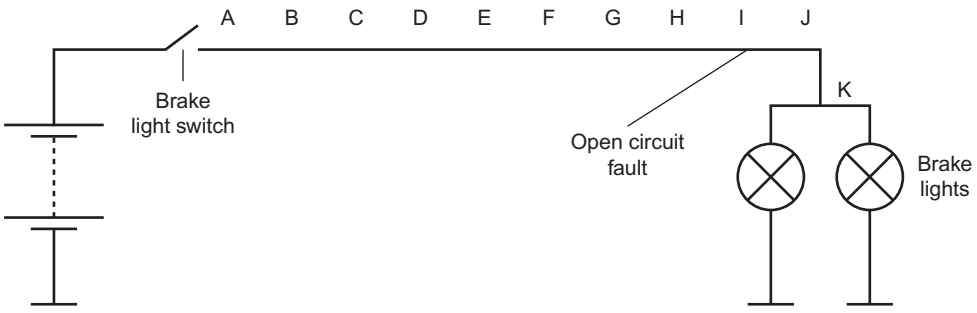


Figure 2.11 Faultf nding by playing the odds – sometimes you get lucky

- We would f nd the fault … In 9 tests

You may choose which method you prefer.

2.5.11 Colour codes and terminal numbers

It is useful to become familiar with a few key wire colours and terminal numbers when diagnosing electrical faults. As seems to be the case for any standardisation a number of colour code systems are in operation.

A system used by a number of manufacturers is based broadly on the information in Table 2.7. After some practice with the use of colour codes the job of the technician is made a lot easier when faultf nding an electrical circuit.

A system now in use almost universally is the terminal designation system in accordance with DIN 72 552. This system is to enable easy and correct connections to be made on the vehicle, particularly in after-sales repairs. Note that the designations are not to identify individual wires but are to def ne the terminals of a device. Listed below are some of the most popular numbers (Table 2.8).

Ford motor company, and many others, now uses a circuit numbering and wire identif cation system. This is in use worldwide and is known as Function-System-Connection (FSC). The system was developed to assist in vehicle development

Table 2.7 Colour codes in use in Europe and elsewhere

Colour	Symbol	Destination/Use
Red	Rt	Main battery feed
White/Black	Ws/Sw	Headlight switch to dip switch
White	Ws	Headlight main beam
Yellow	Ge	Headlight dip beam
Grey	Gr	Sidelight main feed
Grey/Black	Gr/Sw	Left-hand sidelights
Grey/Red	Gr/Rt	Right-hand sidelights
Black/Yellow	Sw/Ge	Fuel injection
Black/Green	Sw/Gn	Ignition controlled supply
Black/White/Green	Sw/Ws/Gn	Indicator switch
Black/White	Sw/Ws	Left-side indicators
Black/Green	Sw/Gn	Right-side indicators
Light Green	LGn	Coil negative
Brown	Br	Earth
Brown/White	Br/Ws	Earth connections
Pink/White	KW	Ballast resistor wire
Black	Sw	Reverse
Black/Red	Sw/Rt	Stop lights
Green/Black	Gn/Sw	Rear fog light

and production processes. However, it is also very useful to help the technician with faultf nding. Many of the function codes are based on the DIN system. Note that earth wires are now black.

The system works as follows: 31S-AC3A || 1.5 BK/RD

Function:
- 31 = ground/earth
- S = additionally switched circuit

System:
- AC = headlamp levelling

Connection:
- 3 = switch connection
- A = branch

Size:
- 1.5 = 1.5 mm^2



Key fact

Further reference should always be made to manufacturer's information for specifc details.

Table 2.8 DIN Terminal numbers (examples)

1	Ignition coil negative
4	Ignition coil high tension
15	Switched positive (ignition switch output)
30	Input from battery positive
31	Earth connection
49	Input to flasher unit
49a	Output from flasher unit
50	Starter control (solenoid terminal)
53	Wiper motor input
54	Stop lamps
55	Fog lamps
56	Headlamps
56a	Main beam
56b	Dip beam
58L	Left-hand sidelights
58R	Right-hand sidelights
61	Charge warning light
85	Relay winding out
86	Relay winding input
87	Relay contact input (change over relay)
87a	Relay contact output (break)
87b	Relay contact output (make)
L	Left side indicators
R	Right side indicators
C	Indicator warning light (vehicle)

Table 2.9 Colour codes table

Code	Colour
BK	Black
BN	Brown
BU	Blue
GN	Green
GY	Grey
LG	Light Green
OG	Orange
PK	Pink
RD	Red
SR	Silver
VT	Violet
WH	White
YE	Yellow

Table 2.10 Ford system codes

Letter	Main system	Examples
D	Distribution systems	DE = earth
A	Actuated systems	AK = wiper/washer
B	Basic systems	BA = charging BB = starting
C	Control systems	CE = power steering
G	Gauge systems	GA = level/pressure/temperature
H	Heated systems	HC = heated seats
L	Lighting systems	LE = headlights
M	Miscellaneous systems	MA = air bags
P	Powertrain control systems	PA = engine control
W	Indicator systems ('indications' not turn signals)	WC = bulb failure
X	Temporary for future features	XS = could mean too much?

Colour:

BK = Black (determined by function 31)
RD = Red stripe (Tables 2.9 and 2.10)

It should be noted that the colour codes and terminal designations given in this section are for illustration only.

2.5.12 Back probing connectors

If you are testing for a supply, for example, at an ECU, then use the probes of your digital meter with care. Connect to the back of the terminals, as this will not



Figure 2.12 Test the voltage by back probing a connector with care

damage the connecting surfaces as long as you do not apply excessive force. Sometimes a pin clamped in the test lead's crocodile/alligator clip is ideal for connecting 'through' the insulation of a wire without having to disconnect it. Figure 2.12 shows this technique.

2.6 Fault codes

2.6.1 Fast and slow

Most modern vehicle management systems carry out self-diagnostic checks on the sensors and actuators that connect to the vehicle ECU(s). A fault in one of the components or its associated circuit causes a code to be stored in the ECU memory. These codes may be described as fast or slow. Some ECUs produce both types.

Most fast codes are now read, or scanned, by a code reader or scanner. However, some earlier systems with fault memory were able to output slow codes as a series of pulses.

An LED, dash warning light, scope or even an analogue voltmeter can be used to read slow codes. Normally, slow codes are output as a series of f ashes that must then be interpreted by looking up the code in a table. The slow codes are normally initiated by shorting two connections on the diagnostic plug and then switching the ignition on. Refer to detailed data before shorting any pins out.

Modern ECUs only use fast codes. This really means that, in the same way we accept that a good digital multimeter is an essential piece of test equipment, it is now necessary to consider a fault code reader in the same way.

If a code reader is attached to the serial port on the vehicle harness, fast and slow codes can be read out from the vehicle computer. These are either displayed in the form of a two-, three- or four-digit output code or if software is used the display is in text format.

Key fact

An LED, dash warning light, scope or even an analogue voltmeter can be used to read slow codes.

Key fact

Modern ECUs only use fast codes.

Definition

DLC: Data link connector
DTC: Diagnostic trouble code.
OBD: On-board diagnostics.
EOBD: European on-board diagnostics.

Most connections for this information are now made to the standard data link connector (DLC), which is a mandatory on-board diagnostics (OBD) item. More on this later.

2.6.2 Fault code examples

A number of codes and descriptions are reproduced here as an example of the detailed information that is available from an OBD2 system (Table 2.11).

Table 2.11 OBD2 DTCs

Code	Description
P0000	SAE Reserved – Usage not allowed except as padding in DTC response message
P0001	Fuel volume regulator control circuit/Open
P0002	Fuel volume regulator control range/Performance
P0003	Fuel volume regulator control circuit low
P0004	Fuel volume regulator control circuit high
P0005	Fuel shutoff valve "A" control circuit/Open
P0006	Fuel shutoff valve "A" control circuit low
P0007	Fuel shutoff valve "A" control circuit high
P0008	Engine position system performance (Bank 1)
P0009	Engine position system performance (Bank 2)
P000A	Intake (A) Camshaft position slow response (Bank 1)
P000B	Exhaust (B) Camshaft position slow response (Bank 1)
P000C	Intake (A) Camshaft position slow response (Bank 2)
P000D	Exhaust (B) Camshaft position slow response (Bank 2)
P000E	Fuel volume regulator control exceeded learning limit
P000F	Fuel system over pressure relief valve activated
P0010	Intake (A) Camshaft position actuator circuit/Open (Bank 1)
P0011	Intake (A) Camshaft position timing – Over-advanced (Bank 1)
P0012	Intake (A) Camshaft position timing – Over-retarded (Bank 1)
P0013	Exhaust (B) Camshaft position actuator circuit/Open (Bank 1)
P0014	Exhaust (B) Camshaft position timing – Over-advanced (Bank 1)
P0015	Exhaust (B) Camshaft position timing – Over-retarded (Bank 1)
P0016	Crankshaft position – Camshaft position correlation (Bank 1 Sensor A)
P0017	Crankshaft position – Camshaft position correlation (Bank 1 Sensor B)
P0018	Crankshaft position – Camshaft position correlation (Bank 2 Sensor A)
P0019	Crankshaft position – Camshaft position correlation (Bank 2 Sensor B)
P001A	Intake (A) Cam profile control circuit/Open (Bank 1)
P001B	Intake (A) Cam profile control circuit Low (Bank 1)

(Continued)

Table 2.11 (Continued)

Code	Description
P001C	Intake (A) Cam profile control circuit High (Bank 1)
P001D	Intake (A) Cam profile control circuit/Open (Bank 2)
P001E	Intake (A) Cam profile control circuit Low (Bank 2)
P001F	Intake (A) Cam profile control circuit High (Bank 2)
P0020	Intake (A) Camshaft position actuator circuit/Open (Bank 2)
P0021	Intake (A) Camshaft position timing – Over advanced (Bank 2)
P0022	Intake (A) Camshaft position timing – Over retarded (Bank 2)
P0023	Exhaust (B) Camshaft position actuator circuit/Open (Bank 2)
P0024	Exhaust (B) Camshaft position timing – Over advanced (Bank 2)
P0025	Exhaust (B) Camshaft position timing – Over retarded (Bank 2)
P0026	Intake valve control solenoid circuit range/Performance (Bank 1)
P0027	Exhaust valve control solenoid circuit range/Performance (Bank 1)
P0028	Intake valve control solenoid circuit range/Performance (Bank 2)
P0029	Exhaust valve control solenoid circuit range/Performance (Bank 2)
P002A	Exhaust(B) Cam profile control circuit/Open (Bank 1)
P002B	Exhaust (B) Cam profile control circuit Low (Bank 1)
P002C	Exhaust (B) Cam profile control circuit High (Bank 1)
P002D	Exhaust (B) Cam profile control circuit/Open (Bank 2)
P002E	Exhaust (B) Cam profile control circuit Low (Bank 2)
P002F	Exhaust (B) Cam profile control circuit High (Bank 2)
P0030	HO2S Heater control circuit (Bank 1 Sensor 1)
P0031	HO2S Heater control circuit Low (Bank 1 Sensor 1)
P0032	HO2S Heater control circuit High (Bank 1 Sensor 1)
P0033	Turbocharger/Supercharger bypass valve "A" control circuit/Open
P0034	Turbocharger/Supercharger bypass valve "A" control circuit low
P0035	Turbocharger/Supercharger bypass valve "A" control circuit high
P0036	HO2S Heater control circuit (Bank 1 Sensor 2)
P0037	HO2S Heater control circuit low (Bank 1 Sensor 2)
P0038	HO2S Heater control circuit high (Bank 1 Sensor 2)

2.6.3 Clearing

Fault codes can be cleared from the ECU memory in two ways:

1. Using the facilities of a fault code reader (scanner) to clear the memory;
2. Disconnecting the battery earth lead for about two minutes (on some systems this does not work).

The f rst method is clearly recommended because disconnecting the battery will also ‘reset’ many other functions such as the radio code, the clock and even the learnt or adaptive functions in the ECUs.

2.7 Systems

2.7.1 What is a system?

Def nition

System: From the Latin *systēma*, in turn from Greek *σύστημα systēma*, system is a set of interacting or interdependent system components forming an integrated whole.

System is a word used to describe a collection of related components, which interact as a whole. A motorway system, the education system or computer systems are three varied examples. A large system is often made up of many smaller systems which in turn can each be made up of smaller systems and so on. Figure 2.13 shows how this can be represented in a visual form. One further def nition: ‘A group of devices serving a common purpose’.

Using the systems approach helps to split extremely complex technical entities into more manageable parts. It is important to note, however, that the links between the smaller parts and the boundaries around them are also very important. System boundaries will overlap in many cases.

The modern motor vehicle is a complex system and in itself forms just a small part of a larger transport system. It is the ability for the motor vehicle to be split into systems on many levels which aids both in its design and construction. The systems approach helps in particular with understanding of how something works and further how to go about repairing it when it doesn’t.

2.7.2 Vehicle systems

Splitting the vehicle into systems is not an easy task because it can be done in many different ways. A split between mechanical systems and electrical systems would seem a good start. However, this division can cause as many problems as it solves. For example, in which half do we put anti-lock brakes, mechanical or electrical? The answer is of course both. Nonetheless, it still makes it easier to be able to just consider one area of the vehicle and not have to try to comprehend the whole.

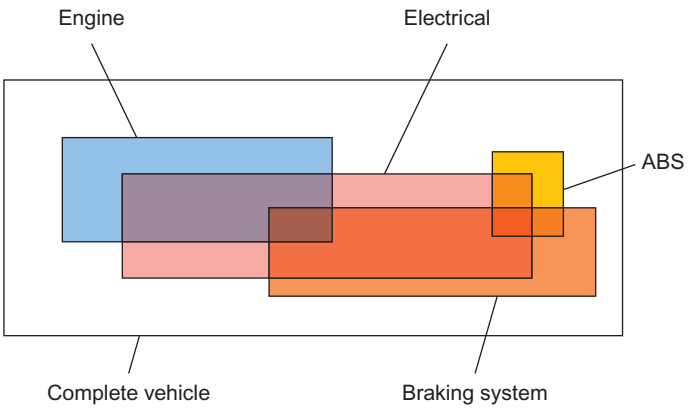


Figure 2.13 Systems in systems representation

Once a complex set of interacting parts such as a motor vehicle has been ‘systemised’, the function or performance of each part can be examined in more detail. In other words, what each part of the system should do in turn helps to determine how each part actually works. It is again important to stress that the links and interactions between various sub-systems are a very important consideration. Examples of this would be how the power demands of the vehicle lighting system will have an effect on the charging system operation, or in the case of a fault, how an air leak from a brake servo could cause a weak air/fuel ratio.

To further analyse a system whatever way it has been sub-divided from the whole, consideration should be given to the inputs and the outputs of the system. Many of the complex electronic systems on a vehicle lend themselves to this form of analysis. Considering the ECU of the system as the control element and looking at its inputs and outputs is the recommended approach.

2.7.3 Open-loop systems

An open-loop system is designed to give the required output whenever a given input is applied. A good example of an open-loop vehicle system would be the headlights. With the given input is the switch being operated, the output required is that the headlights will be illuminated.

This can be taken further by saying that an input is also required from the battery and a further input from, say, the dip switch. The feature, which determines that a system is open loop, is that no feedback is required for it to operate. Figure 2.14 shows this example in block diagram form.

2.7.4 Closed-loop systems

A closed-loop system is identif ed by a feedback loop. It can be described as a system where there is a possibility of applying corrective measures if the output is not quite what is wanted. A good example of this in a vehicle is an automatic temperature control system. The interior temperature of the vehicle is determined by the output from the heater which is switched on or off in response to a signal from a temperature sensor inside the cabin. The feedback loop is the fact that the output from the system, temperature, is also an input to the system. This is represented by Figure 2.15.

The feedback loop in any closed-loop system can be in many forms. The driver of a car with a conventional heating system can form a feedback loop by turning



Figure 2.14 Open-loop system

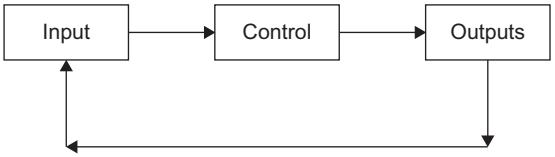


Figure 2.15 Closed-loop system

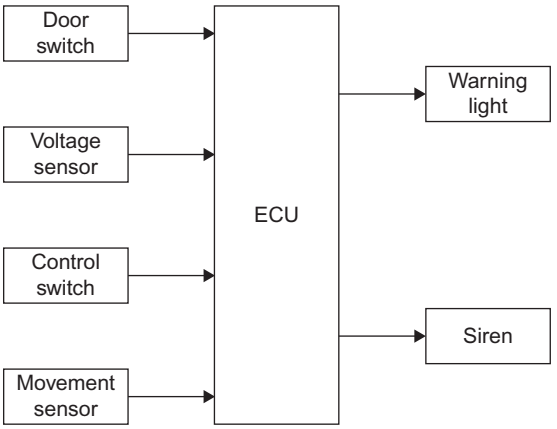


Figure 2.16 Block diagram

Key fact

A closed-loop system always has a feedback loop that may be negative or positive.

the heater down when he or she is too hot and turning it back up when cold. The feedback on an ABS system is a signal that the wheel is locking, where the system reacts by reducing the braking force – until it stops locking, when braking force can be increased again – and so on to maintain a steady state.

2.7.5 Block diagrams

Another secret to good diagnostics is the 'block diagram' approach. Most systems can be considered as consisting of 'inputs to a control which has outputs'. This technique means that complex systems can be considered in manageable 'chunks'. It is similar to the black box method but just a different approach.

Many complex vehicle electronic systems can be represented as block diagrams. In this way several inputs can be shown supplying information to an ECU that in turn controls the system outputs. As an example of this, consider the operation of a vehicle alarm system (Figure 2.16). In its simplest form the inputs would be the 'sensors' (such as door switches) and the 'outputs' the actuators (such as the siren). The 'control' section is the alarm ECU.

The diagnostic approach is that if all the sensors are providing the correct information to the control and the actuators respond when tested, then the fault must be the control unit. If a sensor does not produce the required information then the fault is equally evident.

2.8 Data sources

2.8.1 Introduction

Key fact

The best source of data is the manufacturer but other companies are now able to supply very good information.

Data is available from a number of sources; clearly the best being direct from the manufacturer. However, for most 'general' repair workshops other sources have to be found. Most sources are now either online or supplied on CD/DVD. However, some useful 'data books' are still available (Figure 2.17).

Examples of the type of data necessary for diagnostic and other work are as follows:

- Component specif cation (resistance, voltage output, etc.)
- Diagnostics charts

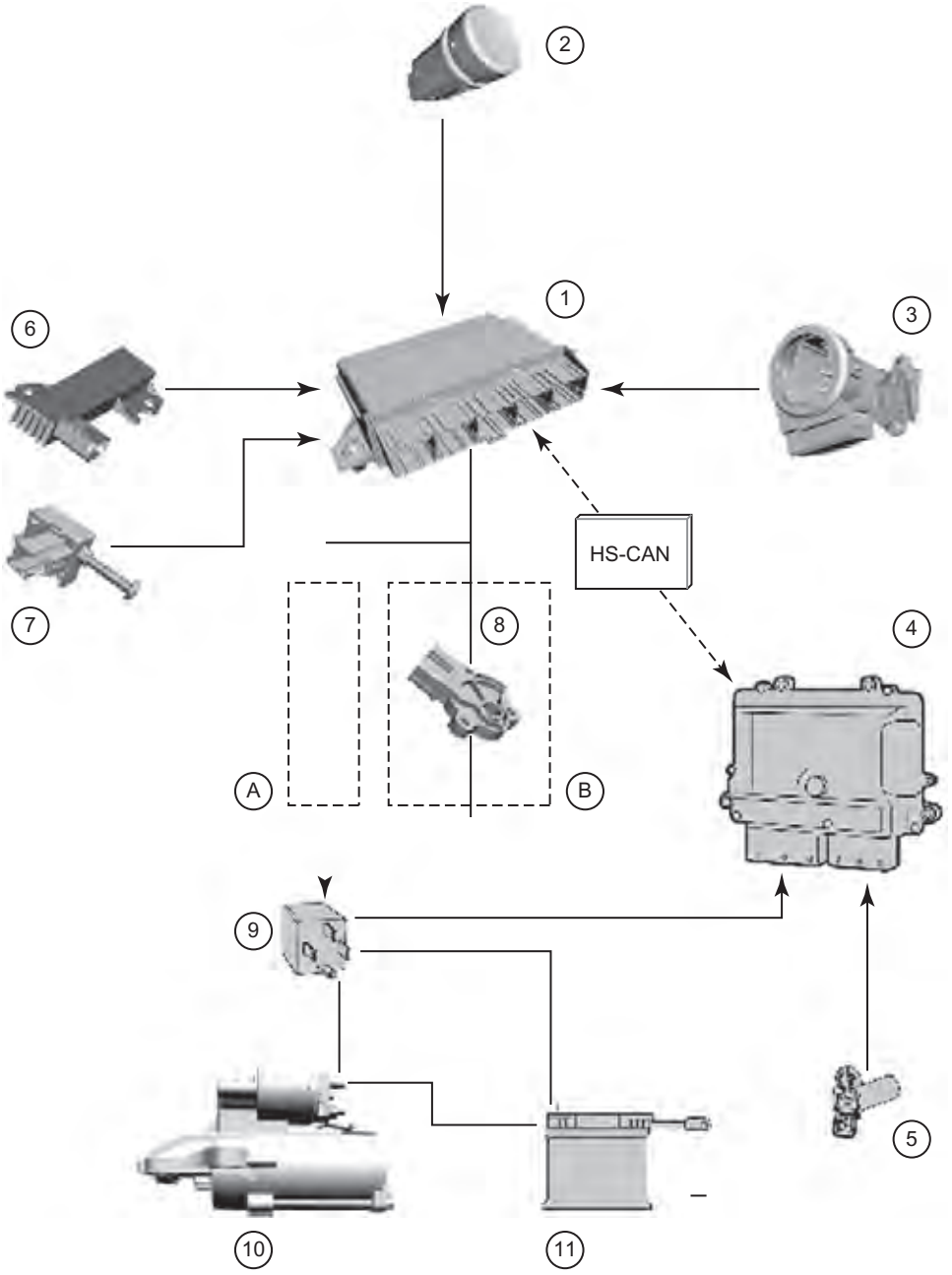


Figure 2.17 Example of a manufacturer's data (Ford): Keyless starting system: 1 – keyless vehicle module; 2 – Start/Stop button; 3 – electronic steering lock; 4 – powertrain control module; 5 – crank sensor; 6 – keyless vehicle antenna; 7 – vehicles with manual transmission: clutch pedal position switch/vehicles with automatic transmission: stoplamp switch; 8 – the TR sensor; 9 – starter relay; 10 – starter motor; 11 – battery. (Source: Ford Motor Company)

- Circuit diagrams
- Adjustment data
- Timing belt f tting data
- Component location
- Repair times
- Service schedules



Figure 2.18 Standard data book (Source: Autodata)

2.8.2 Autodata

One of the best known companies for supplying automotive data is Autodata, both in the United Kingdom, United States and elsewhere. This information, presented as books, on the Web and on CDs, is well known and well respected (Figure 2.18).

Very comprehensive information is available ranging from the standard 'data book' to full vehicle circuit diagrams and engine management (and other systems) diagnostic test routines. The online system is particularly useful. Visit www.autodata.ltd.uk for more information.

Information about testing procedures is available as shown in Figure 2.19. These sheets include test data as well as test procedures related to specif c vehicles or systems (Figure 2.20).

2.8.3 Bosch ESItronic

There are already over 30 million registered cars in the United Kingdom and over 240 million in the United States. Of course this includes older vehicles but all of

PORSCHE	Technical Data				Autodata
	1	2	3	4	5
Vehicle Identification					
Model	944S	944 Turbo	944 S2	928 GT	928 S4
Engine specially tuned for		R.Cat	R.Cat	R.Cat	R.Cat
Year	1986-89	1989-93	1989-93	1989-92	1989-94
Engine Code	M44/04	M44/52	M44/41	M28/47	M28/41/42
No. of cylinders/Type	4/OHC	4/OHC	4/OHC	8/OHC	8/OHC
Capacity cm³	2479	2479	2990	4957	4957
Output kW (DIN hp) rpm	140 (190) 6000	184 (250) 6000	155 (211) 5800	243 (330) 6200	235 (320) 6000
Minimum octane rating RON	95	95	95	95	95
Ignition system Description	Map-h	Map-h	Map-h	Map-i	Map-i
Trigger location	Crankshaft	Crankshaft	Crankshaft	Crankshaft	Crankshaft
Fuel system Make	Bosch	Bosch	Bosch	Bosch	Bosch
Type	Motronic	Motronic	Motronic	LH-Jetronic	LH-Jetronic
Description	MFI-i	MFI-i	MFI-i	MFI-i	MFI-i
Air metering Type	Flow	Flow	Flow	Mass	Mass
Combined ignition and fuel ECU	Yes	Yes	Yes	No	No
Diagnostic socket	Yes	Yes	Yes	Yes	Yes
Tuning and emissions			■		■
Ignition coil supply voltage V	12.0	12.0	12.0	11.0	12.0
Primary resistance Ω	0.4-0.6	0.4-0.6	0.4-0.6	0.4-0.6	0.4-0.6
Secondary resistance Ω	5000-7200	5000-7200	5000-7200	5000-7000	5000-7200
Firing order	1-3-4-2	1-3-4-2	1-3-4-2	1-3-7-2-6-5-4-8	1-3-7-2-6-5-4-8
Ignition distributor (ECU) no.	(0 261 200 080)	(0 261 200 089)	(0 261 200 195)	(0 227 400 164)	(0 227 400 034)
Ignition timing BTDC °Engine/rpm	10a3/840	5a3/840	10a3/840	10a2/775	10a2/675
alternative °Engine/rpm	–	–	–	–	–
o without + with vacuum	o	–	–	–	o
Ignition advance checks °Engine/rpm	ECU controlled	ECU controlled	ECU controlled	ECU controlled	ECU controlled
a = without vacuum and basic timing °Engine/rpm	–	–	–	–	–
b = without vacuum with basic timing °Engine/rpm	–	–	–	–	–
c = with vacuum and basic timing °Engine/rpm	–	–	–	–	–
Vacuum advance range °Engine	–	–	–	–	–
Idle speed rpm	840±40	840±40	840±40	775±25	675±25
alternative rpm	–	–	–	–	–
Oil temperature for CO test °C	90	90	90	90	90
CO content at idle - tail pipe Vol.%	1.0±0.5	0.5 Max	0.5 Max	0.5 Max	0.5 Max
- sample pipe Vol.%	–	0.4-0.8	0.4-0.8	0.4-1.2	0.4-1.2
CO_2/O_2 content at idle speed Vol.%	13-16/0.5-2.0	14.5-16/0.1-0.5	14.5-16/0.1-0.5	14.5-16/0.1-0.5	14.5-16/0.1-0.5
HC content at idle speed ppm	300	100	100	100	100
Increased idle speed for CO test rpm	–	2500-2800	2500-2800	2500-2800	2500-2800
CO content at increased idle speed Vol.%	–	0.3	0.3	0.3	0.3
Lambda at increased idle speed λ	–	0.97-1.03	0.97-1.03	0.97-1.03	0.97-1.03
Service checks and adjustments					
Spark plugs Make	Bosch	Bosch	Bosch	Bosch	Bosch
(also see Spark Plugs list) Type	WR5DC	WR7DC	WR5DC	WR7DC	WR7DC
Electrode gap mm	0.7	0.7	0.7	0.7	0.6-0.8
Valve clearances - inlet mm	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic
- exhaust mm	Hydraulic	Hydraulic	Hydraulic	Hydraulic	Hydraulic
Compression pressure bar	–	–	–	–	–
Oil pressure bar / rpm	3.5/6000	3.5/6000	3.5/6000	5/4000	5/5000
Lubricants and capacities					
Engine oil grade SAE (API)	15W/40 (SF)	15W/40 (SF)	15W/40 (SF)	15W/40 (SF)	15W/40 (SF)
Engine with filter litres	6.5	7.0	7.0	7.5	7.5
Gearbox oil grade SAE	75W/90	75W/90	75W/90	75W/90	75W/90
4/5 speed litres	2.0	2.0	7.0	4.5	4.5
Automatic transmission fluid Type	Dexron II D	–	–	–	Dexron II D
refill litres	6.0	–	–	–	7.3
Differential oil grade SAE	90W	–	–	–	90W
litres/gear litres	1.0 (AT)	–	–	–	1.30 (AT)

POR 3 ■ = refer to Technical Information at end of this manufacturer X = setting not adjustable

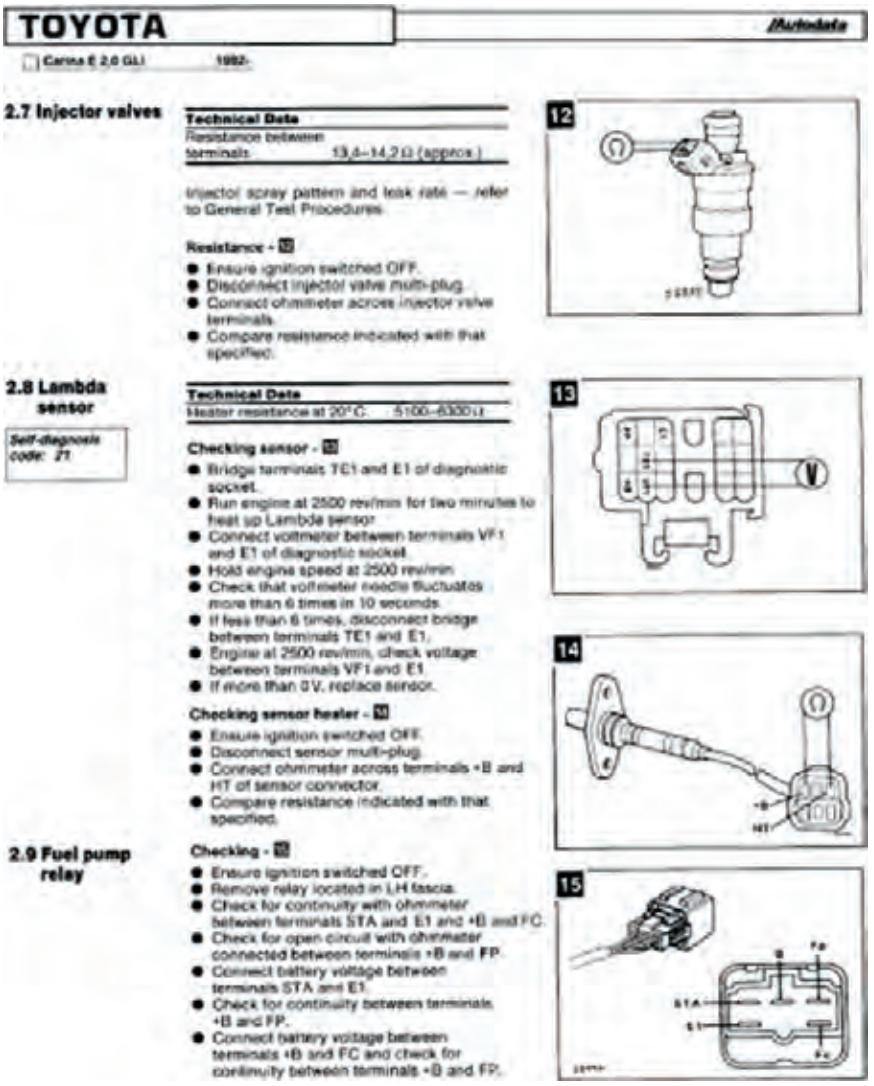
Figure 2.19 Example data sheet (Source: Autodata)

the newer ones (still 10s of millions) have engine management systems. These need quality test equipment to diagnose faults and system failures. Ineffective diagnostic work inevitably leads to vehicle problems, dissatisf ed customers and labour costs which far exceed a realistic invoice value for the workshop.

Good data will help reduce errors and increase satisfaction. The Bosch ESItronic system (Figure 2.21) runs from a DVD and as well as information about test procedures and test results, other details such as service data are included.

Key fact

There are already over 30 million registered cars in the United Kingdom and over 240 million in the United States.



TOYOTA

Autodata

Carina E 2.0 GLi 1992-

2.7 Injector valves

Technical Data

Resistance between terminals 13,6–14,2 Ω (approx.)

Injector spray pattern and leak rate — refer to General Test Procedures.

Resistance -

- Ensure ignition switched OFF.
- Disconnect injector valve multi-plug.
- Connect ohmmeter across injector valve terminals.
- Compare resistance indicated with that specified.

2.8 Lambda sensor

Self-diagnosis code: 21

Technical Data

Heater resistance at 20°C 5100–6300 Ω

Checking sensor -

- Bridge terminals TE1 and E1 of diagnostic socket.
- Run engine at 2500 rev/min for two minutes to heat up Lambda sensor.
- Connect voltmeter between terminals VF1 and E1 of diagnostic socket.
- Hold engine speed at 2500 rev/min.
- Check that voltmeter needle fluctuates more than 6 times in 10 seconds.
- If less than 6 times, disconnect bridge between terminals TE1 and E1.
- Engine at 2500 rev/min, check voltage between terminals VF1 and E1.
- If more than 0V, replace sensor.

Checking sensor heater -

- Ensure ignition switched OFF.
- Disconnect sensor multi-plug.
- Connect ohmmeter across terminals +B and HT of sensor connector.
- Compare resistance indicated with that specified.

2.9 Fuel pump relay

Checking -

- Ensure ignition switched OFF.
- Remove relay located in LH fascia.
- Check for continuity with ohmmeter between terminals STA and E1 and +B and FC.
- Check for open circuit with ohmmeter connected between terminals +B and FP.
- Connect battery voltage between terminals STA and E1.
- Check for continuity between terminals +B and FP.
- Connect battery voltage between terminals +B and FC and check for continuity between terminals +B and FP.

12

13

14

15

Figure 2.20 Fuel injection testing example (Source: Autodata)



Figure 2.21 ESItronic data (Source: Bosch Media)

This data system can be used in conjunction with the Bosch diagnostic tool discussed in the next chapter.

2.9 Summary

Both of the previously mentioned companies as sources of data are excellent – and essential. It is possible to carry out diagnostic work without this, but much more diff cult and less reliable. The money for good data will be well spent.

CHAPTER



Tools and equipment

3.1 Basic equipment

3.1.1 Introduction

Diagnostic techniques are very much linked to the use of test equipment. In other words, you must be able to interpret the results of tests. In most cases this involves comparing the result of a test to the reading given in a data book or other source of information. By way of an introduction, Table 3.1 lists some of the basic words and descriptions relating to tools and equipment.

3.1.2 Basic hand tools

You will not learn how to use tools by reading a book; it is clearly a very practical skill. However, you can follow the recommendations made here and by the manufacturers. Even the range of basic hand tools is now quite daunting and very expensive. It is worth repeating the general advice given by Snap-on for the use of hand tools:

- Only use a tool for its intended purpose.
- Always use the correct size tool for the job you are doing.
- Pull a wrench rather than pushing whenever possible.
- Do not use a f le or similar, without a handle.
- Keep all tools clean and replace them in a suitable box or cabinet.
- Do not use a screwdriver as a pry bar.
- Always follow manufacturer's recommendations (you cannot remember everything).
- Look after your tools and they will look after you!

3.1.3 Accuracy of test equipment

Accuracy can be described in a number of slightly different ways:

- careful and exact;
- free from mistakes or errors;
- precise;
- adhering closely to a standard.

Consider measuring a length of wire with a steel rule. How accurately could you measure it? To the nearest 0.5 mm? This raises a number of issues. First, you could make an error reading the ruler. Second, why do we need to know

Advanced Automotive Fault Diagnosis.
© 2012 Tom Denton. Published by Routledge. All rights reserved.

Table 3.1 Tools and equipment

Hand tools	Spanners, hammers, screwdrivers and all the other basic bits
Special tools	A collective term for items not held as part of a normal tool kit, items required for just one specific job
Test equipment	In general, this means measuring equipment. Most tests involve measuring something and comparing the result of that measurement to data. The devices can range from a simple ruler to an engine analyser
Dedicated test equipment	Some equipment will only test one specific type of system. The large manufacturers supply equipment dedicated to their vehicles. For example, a diagnostic device which plugs in to a certain type of fuel injection electronic control unit (ECU)
Accuracy	Careful and exact, free from mistakes or errors and adhering closely to a standard
Calibration	Checking the accuracy of a measuring instrument
Serial port	A connection to an ECU, a diagnostic tester or computer, for example. Serial means the information is passed in a 'digital' string, like pushing black and white balls through a pipe in a certain order
Code reader or scanner	This device reads the 'black and white balls' mentioned above or the on–off electrical signals, and converts them in to language we can understand
Combined diagnostic and information system	Now usually PC based, these systems can be used to carry out tests on vehicle systems, and they also contain an electronic workshop manual. Test sequences guided by the computer can also be carried out
Oscilloscope	The main part of 'scope' is the display, which is like a TV or computer screen. A scope is a voltmeter but instead of readings in numbers it shows the voltage levels by a trace or mark on the screen. The marks on the screen can move and change faster allowing us to see the way voltages change

Definition

Accuracy: How close the measured value of something is to the actual value.

Definition

Resolution: The 'fineness' with which a measurement can be made.

the length of a bit of wire to the nearest 0.5 mm? Third, the ruler may stretch and not give the correct reading!

The first and second issues can be dispensed with by knowing how to read the test equipment correctly and also knowing the appropriate level of accuracy required. A micrometer for a plug gap? A ruler for valve clearances? I think you get the idea. The accuracy of the equipment itself is another issue.

Accuracy is a term meaning how close the measured value of something is to its actual value. For example, if a length of approximately 30 cm is measured with an ordinary wooden ruler, then the error may be up to 1 mm too high or too low. This is quoted as an accuracy of ±1 mm. This may also be given as a percentage, which in this case would be 0.33%.

Resolution or, in other words, the 'fineness', with which a measurement can be made, is related to accuracy. If a steel ruler was made to a very high standard but only had markings of 1/cm, it would have a very low resolution even though the graduations were very accurate. In other words, the equipment is accurate but your reading will not be!

To ensure instruments are, and remain accurate, there are just two simple guidelines:

1. Look after the equipment, a micrometer thrown on the floor will not be accurate.
2. Ensure instruments are calibrated regularly – this means being checked against known good equipment.

Table 3.2 Accurate measurement process

Step	Example
Decide on the level of accuracy required	Do we need to know that the battery voltage is 12.6V or 12.635V
Choose the correct instrument for the job	A micrometer to measure the thickness of a shim
Ensure the instrument has been looked after and calibrated when necessary	Most instruments will go out of adjustment after a time. You should arrange for adjustment at regular intervals. Most tool suppliers will offer this service or in some cases you can compare older equipment to new stock
Study the instructions for the instrument in use and take the reading with care. Ask yourself if the reading is about what you expected	Is the piston diameter 70.75 or 170.75mm
Make a note if you are taking several readings	Don't take a chance, write it down

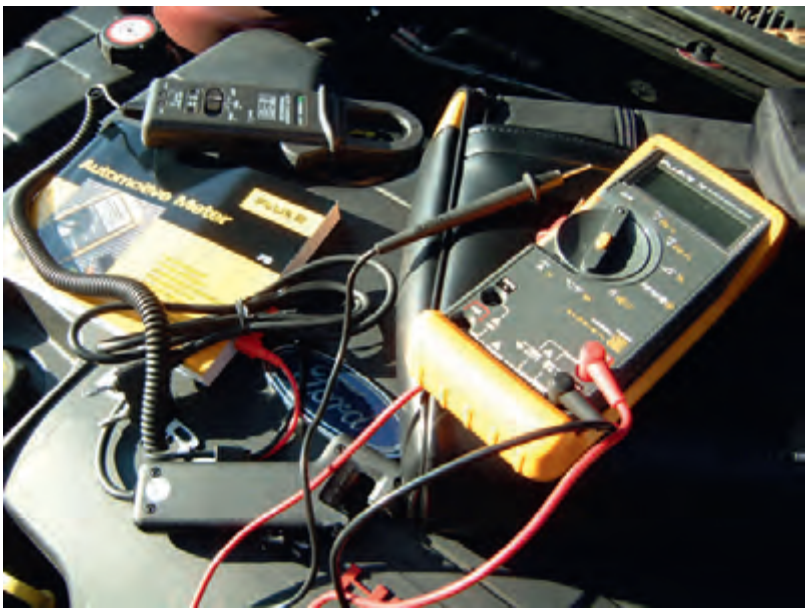


Figure 3.1 Multimeter and accessories

Table 3.2 provides a summary of the steps to ensure a measurement is accurate.

3.1.4 Multimeters

An essential tool for working on vehicle electrical and electronic systems is a good digital multimeter (often referred to as a DMM) (Figure 3.1). Digital meters are most suitable for accuracy of reading as well as available facilities they provide.

The list of functions presented in Table 3.3, broadly in order starting from essential to desirable, should be considered.

A way of determining the quality of a digital multimeter as well as the facilities they provide is to consider the following:

- accuracy;
- loading effect of the meter;
- protection circuits.

Definition

DMM: Digital multimeter

Table 3.3 Multimeter functions

Function	Range	Accuracy
DC voltage	500 V	0.3%
DC current	10 A	1.0%
Resistance	0–10 MΩ	0.5%
AC voltage	500 V	2.5%
AC current	10 A	2.5%
Dwell	3, 4, 5, 6, 8 cylinders	2.0%
RPM	10 000 rpm	0.2%
Duty cycle	% On/off	0.2%/kHz
Frequency	Over 100 kHz	0.01%
Temperature	>9000 °C	0.3% + 30 °C
High current clamp	1000 A (DC)	Depends on conditions
Pressure	3 bar	10.0% of standard scale

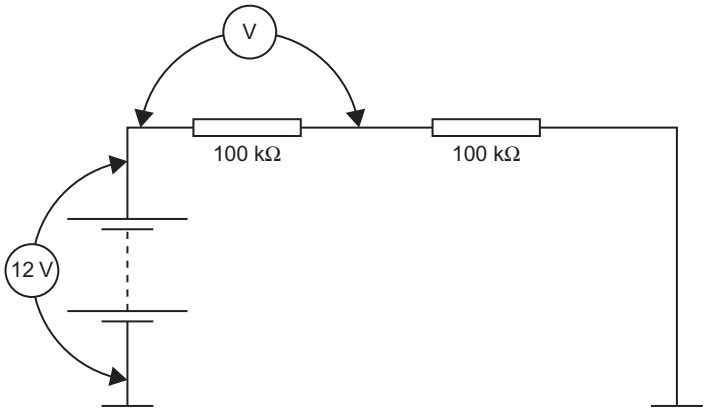


Figure 3.2 Loading effect of a meter

The loading effect is a consideration for any form of measurement. With a multimeter, this relates to the internal resistance of the meter. It is recommended that the internal resistance of a meter should be a minimum of 10 MΩ. This not only ensures greater accuracy but also prevents the meter from damaging sensitive circuits.

Figure 3.2 shows two equal resistors connected in series across a 12 V supply. The voltage across each resistor should be 6 V. However, the internal resistance of the meter will affect the circuit conditions and change the voltage reading. If the resistor values were 100 kΩ, the effect of meter internal resistance would be as follows:

Meter resistance 1 MΩ

The parallel combined value of 1 MΩ and 100 kΩ is 91 kΩ. The voltage drop in the circuit across this would be

$$\frac{91}{(100 + 91)} \times 12 = 5.71\text{V}$$

This is an error of approximately 5%.



Figure 3.3 Logic probe(Source: Maplin)

Meter resistance 10 MΩ

The parallel combined value of 10 MΩ and 100 kΩ is 99 kΩ. The voltage drop in the circuit across this would be

$$\frac{99}{(100 + 99)} \times 12 = 5.97\,\text{V}$$

This is an error of approximately 0.5%.

Of course, understanding accuracy is important, but there are two further skills that are important when using a multimeter: where to put the probes and what the reading you get actually means!

Key fact

An 'invasive measurement' error is in addition to the basic accuracy of the meter.

3.1.5 Logic probe

This device is a useful way of testing logic circuits, but it is also useful for testing some types of sensor. Figure 3.3 shows a typical logic probe. Most types consist of two power supply wires and a metal 'probe'. The display consists of three LEDs labelled 'high', 'low' and 'pulse'. These LEDs light up together with an audible signal in some cases, when the probe touches either a high, low or pulsing voltage. Above or below 2.5 V is often used to determine high or low on a 5 V circuit.

Key fact

A voltmeter connects in parallel across a circuit

An ammeter connects in series

An ohmmeter connects across a component – but the circuit must be isolated.

3.2 Oscilloscopes

3.2.1 Introduction

There were traditionally two types of oscilloscope; analogue or digital. However, the digital scope is now universal. An oscilloscope draws a graph of voltage (the vertical scale or Y axis) against time (the horizontal scale or X axis).

The trace is made to move across the screen from left to right and then to 'f y back' and start again. The frequency at which the trace moves across the screen is known as the time base, which can be adjusted either automatically or manually.

Key fact

An oscilloscope draws a graph of voltage against time.

The signal from the item under test can either be amplif ed or attenuated (reduced), much like changing the scale on a voltmeter.

The trigger, which starts the trace moving across the screen, can be caused internally or externally. When looking at signals such as ignition voltages, triggering is often external; for example, each time an individual spark f res or each time number one spark plug f res.

The voltage signal under test is A/D converted and the time base is a simple timer or counter circuit. Because the signal is plotted digitally on a screen from data in memory, the picture can be saved, frozen or printed. The speed of data conversion and the sampling rate as well as the resolution of the screen are very important to ensure accurate results.

Def nition

USB: Universal serial bus.

The highly recommended Pico Automotive Diagnostics kit (Figure 3.4) turns a laptop or desktop PC into a powerful automotive diagnostic tool for faultf nding sensors, actuators and electronic circuits.

The high-resolution PC oscilloscope connects to a USB port on a PC and can take up to 32 million samples per trace, making it possible to capture complex automotive waveforms – including CAN bus and FlexRay signals (more on this later) – and then zoom in on areas of interest. Being PC based, these waveforms can then be saved for future reference, printed or emailed.

The scope can be used to measure and test virtually all of the electrical and electronic components and circuits in any modern vehicle, including

- ignition (primary and secondary);
- injectors and fuel pumps;
- starter and charging circuits;
- batteries, alternators and starter motors;
- lambda, airf ow, knock and MAP sensors;



Figure 3.4 Automotive oscilloscope kit (Source: PicoTech)

- glow plugs/timer relays;
- CAN bus, LIN bus and FlexRay.

This powerful and f exible automotive diagnostic tool has been designed for ease of use, so is equally suitable for both novice and expert users. It is powered directly from the USB port, eliminating the need for power leads or battery packs and making it suitable for use in the workshop or on the road.

Excellent software is included, which means that the user can simply select the sensor or circuit to be tested and the software will automatically load the required settings. It will also give full details of how to connect the scope, along with advice on what the waveform should look like and general technical information on the component being tested.

All the waveforms shown in this book were captured using this piece of equipment. Visit http://www.picoauto.com for more information.

3.2.2 Waveforms

You will f nd the words ‘waveform’, ‘pattern’ and ‘trace’ are used in books and workshop manuals but they mean the same thing. I will try to stick to waveform.

When you look at a waveform on a screen, it is important to remember that the height of the scale represents voltage and the width represents time. Both of these axes can have their scales changed. They are called axes because the ‘scope’ draws a graph of the voltage at the test points over a period of time. The time scale can vary from a few microseconds to several seconds. The voltage scale can vary from a few millivolts to several kilovolts. For most test measurements only two connections are needed just like a voltmeter. The time scale will operate at intervals preset by the user. It is also possible to connect a ‘trigger’ wire so that the time scale starts moving across the screen each time the ignition coil f res, for example. This keeps the display in time with the speed of the engine. Figure 3.5 shows an example waveform.

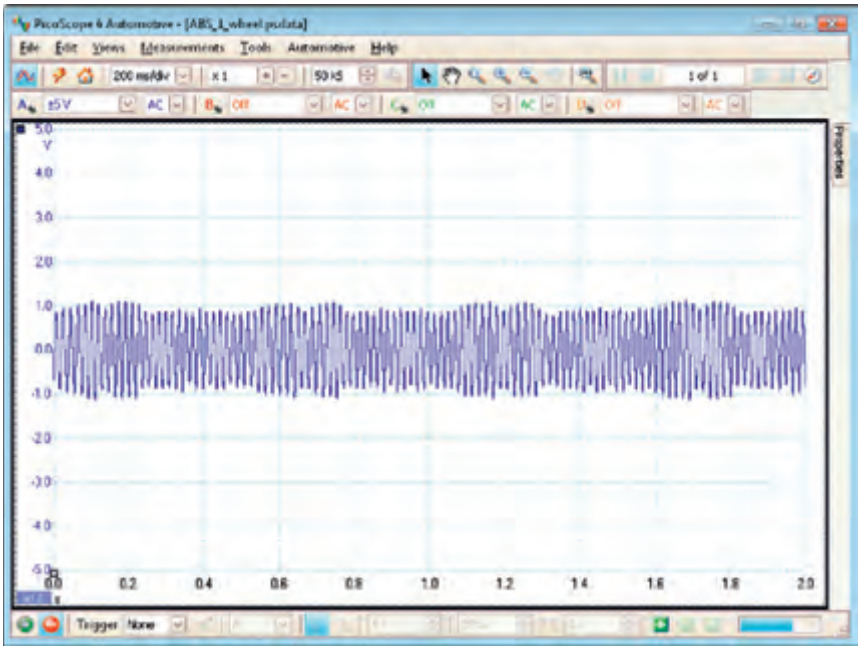


Figure 3.5 ABS waveform captured on a PicoScope®

Most of the waveforms shown in various parts of this book are from a correctly operating vehicle but some incorrect ones are also presented for comparison. The skill you will learn by practice is to note when your own measurements vary from the ideal – and how to interpret them.

Def nition

OBD: On-board diagnostics.

3.3 Scanners/Fault code readers and analysers

Note: Please refer to Chapter 5 for full details about on-board diagnostics (OBD) systems.

3.3.1 On-board diagnostics introduction

OBD is a generic term referring to a vehicle's self-diagnostic and reporting system. OBD systems give the vehicle owner or a technician access to information for various vehicle systems.

The amount of diagnostic information available via OBD has varied considerably since its introduction in the early 1980s. Early versions of OBD would simply illuminate a malfunction indicator light (MIL) if a problem was detected, but did not provide any information about the problem. Modern OBD systems use a standardised digital communications port to provide real-time data in addition to a standardised series of diagnostic trouble codes (DTCs), which allow a technician to identify and remedy faults on the vehicle. The current versions are OBD2 and European OBD2 (EOBD2). The standard OBD2 and EOBD2 are quite similar.

3.3.2 Serial port communications

Most modern vehicle systems now have ECUs that contain self-diagnosis circuits. The information produced is read via a serial link using a scanner.

A special interface, stipulated by one of a number of standards (see section 3.3.3), is required to read the data. The standards are designed to work with a single- or two-wire port allowing many vehicle electronic systems to be connected to a central diagnostic plug. The sequence of events to extract DTCs from the ECU is as follows:

1. Test unit transmits a code word.
2. ECU responds by transmitting a baud rate recognition word.
3. Test unit adopts the appropriate setting.
4. ECU transmits fault codes.

The test unit converts the DTCs to suitable output text. Further functions are possible, which may include the following:

- Identif cation of ECU and system to ensure the test data is appropriate to the system currently under investigation.
- Read out of current live values from sensors. Spurious f gures can be easily recognised. Information such as engine speed, temperature, airf ow and so on can be displayed and checked against the test data.
- System function stimulation to allow actuators to be tested by moving them and watching for suitable response.
- Programming of system changes such as basic idle CO or changes in basic timing can be programmed into the system.



Figure 3.6 Diagnostic data link connector (DLC)

3.3.3 OBD2 signal protocols

Five different signalling protocols are permitted with the OBD2 interface. Most vehicles implement only one of them. It is often possible to deduce the protocol used based on which pins are present on the J1962 connector (Figure 3.6).

Some details of the different protocols are presented here for interest. No need to memorise the details!

SAE J1850 PWM (pulse-width modulation): A standard of Ford Motor Company

- Pin 2: Bus+.
- Pin 10: Bus−.
- High voltage is +5 V.
- Message length is restricted to 12 bytes, including cyclic redundancy check (CRC).
- Employs a multi-master arbitration scheme called 'Carrier Sense Multiple Access with Non-Destructive Arbitration' (CSMA/NDA).

SAE J1850 VPW (variable pulse width): A standard of General Motors

- Pin 2: Bus+.
- Bus idles low.
- High voltage is +7 V.
- Decision point is +3.5 V.
- Message length is restricted to 12 bytes, including CRC.
- Employs CSMA/NDA.

ISO 9141-2: Primarily used by Chrysler, European, and Asian vehicles

- Pin 7: K-line.
- Pin 15: L-line (optional).
- UART signalling.
- K-line idles high, with a 510 Ω resistor to Vbatt.
- The active/dominant state is driven low with an open-collector driver.
- Message length is restricted to 12 bytes, including CRC.

Def nition

Protocol: A set of rules which is used to allow computers to communicate with each other

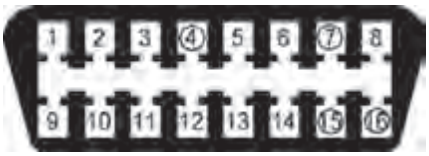


Figure 3.7 Connector pin-out: 4 – battery ground/earth, 7 – K-line, 15 – L-line, 16 – battery positive



Figure 3.8 AutoTap scanner and extension cable

Definition

ISO: International Standards Organisation.

ISO 14230 KWP2000 (Keyword Protocol 2000)

- Pin 7: K-line.
- Pin 15: L-line (optional).
- Physical layer identical to ISO 9141-2.
- Message may contain up to 255 bytes in the data field.

ISO 15765 CAN: The CAN protocol was developed by Bosch for automotive and industrial control. Since 2008, all vehicles sold in the United States (and most others) are required to implement CAN as one of their signalling protocols.

Definition

CAN: Controller area network.

- Pin 6: CAN high
- Pin 14: CAN low

All OBD2 pin-outs use the same connector but different pins, with the exception of pin 4 (battery ground) and pin 16 (battery positive) (Figure 3.7).

3.3.4 AutoTap OBD scanner

Author's Note: This section outlines the use and features of the AutoTap scanner. I have chosen this particular tool as a case study because it provides some very advanced features at a very competitive price. The scanner is designed specifically to work with OBD2 systems. However, it worked fine on all the petrol engined EOBD systems I have used so far. For more information, visit http://www.autotap.com.

Like any professional scanner or code reader, the AutoTap scan tool connects the special OBD2 DLC, which is always accessible from the driver's seat (often on or under the dash) (Figure 3.8). A USB cable makes the scanner connection to a computer. The scanner translates the signals from the vehicle's computer controlled sensors to easy-to-read visual displays. It also reads out any diagnostic trouble codes.

The software also allows the technician (or hobbyist) to choose which parameters or signals they want to see, and whether they are to be viewed as tables, graphs, meters or gauges (Figure 3.9).

It is possible to set the ranges and alarms and pick display colours. Once a screen configuration is created, it can be saved for future use. Different

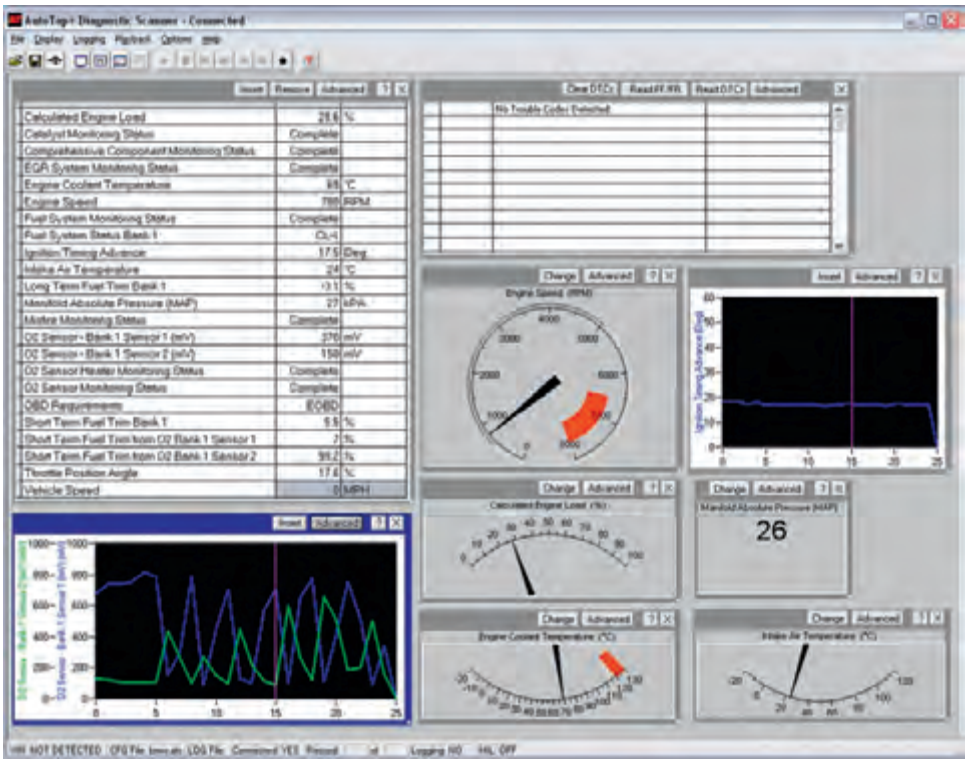


Figure 3.9 Screen grab from the Autel software showing tables, gauges and graphs

screen conf gurations are useful for different vehicles, or perhaps one for major maintenance, one for tuning, one for quick checks at a race track.

Lots of data are provided in easy-to-read views with multiple parameters. Graphs can be used to show short-term logs and gauges for instant readings.

DTCs can be checked immediately on connecting the scanner and starting up the software. This gives the critical info needed in the shortest time possible. When repairs are completed, the tool can be used to turn off the MIL. This light is also described as the check engine light.

Def nition

MIL: Malfunction indicator light.

The software will also log data, for example, during a road test. This is particularly useful for diagnosing intermittent faults. The data can be played back after a road or dynamometer test. It can also be exported to a spreadsheet f le for later analysis.

Overall, to read live data and get access to powertrain (engine-related) system DTCs, this is an excellent piece of equipment.

3.3.5 Bosch KTS diagnostic equipment

Author's Note: This section will outline the use and features of the Bosch KTS 650 diagnostic system. I have chosen this particular tool as a case study because it provides everything that a technician needs to diagnose faults, but at a professional price. The system is a combination of a scanner, multimeter, oscilloscope and information system (when used with Esitronic). For more information, visit http://www.bosch.com.

Modern vehicles are being f tted with more and more electronics. This complicates diagnosis and repair, especially as the individual systems are often interlinked. The work of service and repair workshops is being fundamentally



Figure 3.10 Diagnostic system in use (Source: Bosch Media)



Figure 3.11 Adapter and cable kit (Source: Bosch Media)

changed. Automotive engineers have to continually update their knowledge of vehicle electronics. But this is no longer sufficient on its own. The ever-growing number of electrical and electronic vehicle components is no longer manageable without modern diagnostic technology – such as the latest range of KTS control unit diagnostic testers from Bosch. In addition, more and more of the previously purely mechanical interventions on vehicles now require the use of ECUs – such as the oil change (Figure 3.10).

Vehicle workshops operate in a very competitive environment and have to be able to carry out demanding repair work efficiently, to a high standard and at a competitive price on a wide range of vehicle makes and models. The Bosch KTS control-unit diagnostic testers, used in conjunction with the comprehensive Esitronic workshop software, offer the best possible basis for efficient diagnosis and repair of electrical and electronic components (Figure 3.11). The testers

are available in different versions, suited to the individual requirements of the particular workshop.

The portable KTS 650 with built-in computer and touch-screen can be used anywhere. It has a 20 GB hard drive, a touch-screen and a DVD drive. When being used away from the workshop, the power supply of the KTS 650 comes from the vehicle battery or from rechargeable batteries with one to two hours' service life. For use in the workshop, there is a tough wheeled trolley with a built-in charger unit. In addition to having all the necessary adapter cables, the trolley can also carry an inkjet printer and an external keyboard, which can be connected to the KTS 650 via the usual PC interfaces.

The Esitronic software package accounts for the in-depth diagnostic capacity of the KTS diagnostic testers. For example, with the new common rail diesel systems, even special functions such as quantitative comparison and compression testing can be carried out. This allows for reliable diagnosis of the faulty part and avoids unnecessary dismantling and re-assembly or the removal and replacement of non-faulty parts.

Modern diagnostic equipment is also indispensable when workshops have to deal with braking systems having electronic control systems such as ABS, ASR and ESP. Nowadays, the diagnostic tester may even be needed for bleeding a brake system.

In addition, KTS and Esitronic allow independent workshops to reset the service interval warning, for example, after an oil change or a routine service, or perhaps f nd the correct default position for the headlamps after one or both have been replaced.

Besides the ISO norms for European vehicles and SAE norms for American and Japanese vehicles, the KTS testers can also deal with CAN norms for checking modern CAN bus systems, which are coming into use more and more frequently in new vehicles. The testers are connected directly to the diagnostics socket via a serial diagnostics interface by means of an adapter cable.

The system automatically detects the control unit and reads out the actual values, the error memory and other controller-specif c data. Thanks to a built-in multiplexer, it is even easier for the user to diagnose the various systems in the vehicle. The multiplexer determines the connection in the diagnostics socket so that communication is established correctly with the selected control unit.

The sequence of images in Table 3.4 shows a number of steps taken to diagnose a fault, using the KTS, on a vehicle that had poor running symptoms and in which the MIL was illuminated.

3.3.6 Engine analysers

Some form of engine analyser has become an almost essential tool for fault f nding modern vehicle engine systems. The latest machines are now generally based around a personal computer. This allows more facilities that can be added to by simply changing the software. However, the latest more portable systems such as the Pico Automotive kit will now do as many tests as the engine analyser, currently with the exception of exhaust emissions.

Although engine analysers are designed to work specif cally with the motor vehicle, it is worth remembering that the machine consists basically of three parts (Figure 3.19):

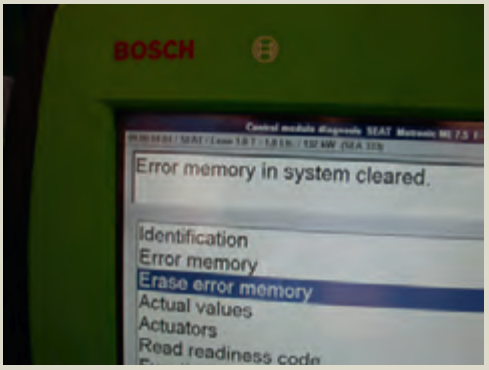
- multimeter;
- gas analyser;
- oscilloscope.

Table 3.4 Fault diagnosis with the KTS

The first step in this procedure was to connect the equipment to the car's diagnostic socket. The ignition should be off when the connection is made and then switched on	 **Figure 3.12** Connect the serial lead to the diagnostic socket
On this system the data for a wide range of vehicles is included on the system. The particular make and engine etc. can be selected from the menu system	 **Figure 3.13** Choose the vehicle type
The standard test for stored DTCs was run and the result suggested that there was a fault with the air sensor. The specific fault was that the signal value was too low. No real surprise as we had disconnected the sensor to simulate a fault	 **Figure 3.14** Take a readout from the control unit memory (DTC display)
This is the connection that was causing the problems. Further information about its pin configuration can be looked up in the Esitronic database	 **Figure 3.15** Airflow sensor connection

(*Continued*)

Table 3.4 (Continued)

The system also provides typical readings that should be obtained on different pins; for example, the supply and earth as well as the signal outputs Additional tests can be carried out to determine the fault	 **Figure 3.16** Esitronic information for the airflow sensor
The faulty connection was repaired and general checks carried out to ensure no other components had been disturbed during the testing and repair process	 **Figure 3.17** Make repairs
The final task is to clear the fault code memory and turn off the MIL Road tests showed that the fault had been rectified	 **Figure 3.18** Erase the fault from the memory

This is not intended to imply that other tests available such as cylinder balance are less valid, but to show that the analyser is not magic, it is just able to present results of electrical tests in a convenient way so as to allow diagnosis of faults. The key component of any engine analyser is the oscilloscope facility, which allows the user to 'see' the signal under test.

The trend with engine analysers seems to be to allow both guided test procedures with pass/fail recommendations for the less skilled technician and freedom to test any electrical device using the facilities available in any reasonable way. This is more appropriate for the highly skilled technician. Some of the routines available on modern engine analysers are listed below:

Tune-up: A full prompted sequence that assesses each component in turn with results and diagnosis displayed at the end of each component test. Stored data



Figure 3.19 Engine analysers

allows pass/fail diagnosis by automatically comparing results of tests with data on the disk. Printouts can be taken to show work completed.

Symptom analysis: This allows direct access to specif c tests relating to reported driveability problems.

Waveforms: A comprehensive range of digitised waveforms can be displayed with colour highlights (Table 3.5). The display can be frozen or recalled to look for intermittent faults. A standard lab scope mode is available to allow examination of electronic fuel injection (EFI) or ABS traces for example. Printouts can be made from any display. An interesting feature on some systems is 'transient capture', which ensures even the fastest spikes and intermittent signals are captured and displayed for detailed examination.

Adjustments: Selecting specif c components from a menu can make simple quick adjustments. Live readings are displayed appropriate to the selection.

UK MOT emissions test: Full MOT procedure tests are integrated and displayed on the screen with pass/fail diagnosis to the department of transport specif cations, for both gas analysis and diesel smoke, if appropriate options are f tted. The test results include engine rpm and oil temperature as well as the gas readings. All these can be printed for garage or customer use.

Engine analyser connections to the vehicle are similar for most equipment manufacturers (Table 3.6).

Table 3.5 Typical waveforms that can be displayed on most analysers and automotive oscilloscopes

Primary	Secondary	Diagnostic	Cylinder test
Primary waveform	Secondary waveform	Voltage waveform	Vacuum waveform
Primary parade waveform	Secondary parade waveform	Lab scope waveform	Power balance waveform
Dwell bar graph	kV histogram	Fuel injector waveform	Cylinder time balance bar graph
Duty cycle/Dwell bar graph	kV bar graph	Alternator waveform	Cylinder shorting even/odd bar graph
Duty cycle/Voltage bar graph	Burn time bar graph		Cranking amps bar graph

Table 3.6 Analyser connections

Connection	Purpose or one example of use
Battery positive	Battery and charging voltages
Battery negative	A common earth connection
Coil positive	To check supply voltage to coil
Coil negative (adapters are available for DIS)	To look at dwell, rpm and primary waveforms
Coil high-tension lead clamp (adapters are available for DIS)	Secondary waveforms
Number one cylinder plug lead clamp	Timing light and sequence of waveforms
Battery cable amp clamp	Charging and starting current
Oil temperature probe (dip stick hole)	Oil temperature
Vacuum connection	Engine load
Exhaust pipe	Emissions testing

3.4 Emission testing

3.4.1 Introduction

Checking the exhaust emissions of a vehicle has three main purposes:

1. ensure optimum performance;
2. comply with regulations and limits;
3. provide diagnostic information.

There are many different exhaust testing systems available.

3.4.2 Exhaust gas measurement

It has now become standard to measure four of the main exhaust gases, namely

- carbon monoxide (CO);
- carbon dioxide (CO_2);
- hydrocarbons (HC);
- oxygen (O_2).

Table 3.7 Exhaust examples

Reading	CO%	HCppm	CO_2%	O_2%	Lambda (λ)	AFR
Before catalyst	0.6	120	14.7	0.7	1.0	14.7
After catalyst	0.2	12	15.3	0.1	1.0	14.7

Key fact

The Greek symbol lambda (λ) represents the ideal air/fuel ratio (AFR) of 14.7:1 by mass.

On many analysers, lambda value and the air/fuel ratio (AFR) are calculated and displayed in addition to the four gases. The Greek symbol lambda (λ) is used to represent the ideal AFR of 14.7:1 by mass; in other words, just the right amount of air to burn up all the fuel. Table 3.7 lists gas, lambda and AFR readings for a closed loop lambda control system, before (or without) and after the catalytic converter. These are applicable for a modern engine in excellent condition and are a guide only – always check current data for the vehicle you are working on.

The composition of exhaust gas is now a critical measurement, hence a certain degree of accuracy is required. To this end, the infrared measurement technique has become the most suitable for CO, CO_2 and HC. Each individual gas absorbs infrared radiation at a specif c rate. Oxygen is measured by electro-chemical means in much the same way as the on-vehicle lambda sensor.

Accurate measurement of exhaust gas is not only required for annual tests but is essential to ensure an engine is correctly tuned. Table 3.7 lists typical values measured from a car exhaust. Note the toxic HC and CO emissions, although small, are nonetheless dangerous.

3.4.3 Exhaust analyser

The facilities of an exhaust analyser produced by Bosch are outlined here.

The measuring system shown in Figures 3.20 and 3.21 can be used for petrol/gasoline, diesel and natural gas vehicles (a statutory requirement in Germany). It is designed for quick and mobile use in workshops and is a robust design. It measures the usual four gases, weighs less than 15 kg and can be ready for operation in just a few minutes. The system is controlled by software, which takes users through the test sequence. The device can be serviced by users themselves every six months.

Def nition

Bluetooth: A proprietary open wireless protocol for exchanging data over short distances from xed and mobile devices, creating personal area networks (PANs).

The system measures the HC, CO, CO_2 and O_2 exhaust components for petrol/gasoline engines. It can also be expanded to measure nitrogen oxide (NO), if necessary. It records engine speed and temperature. Adding a smoke opacity measuring device means exhaust gas analyses can be carried out on diesel vehicles. Linking with the KTS (Section 3.3.5) allows important OBD engine and transmission control unit data as well as the gases to be read. The laptop and KTS can be connected via a cable or Bluetooth.

3.4.4 Emission limits

Limits and regulations relating to exhaust emissions vary in different countries and in different situations. For example, in the United Kingdom, certain limits have to be met during the annual test. The current test default limits (for vehicles since September 2002 f tted with a catalytic converter) are as follows:

- Minimum oil temperature (60 °C)
- Fast idle (2500–3000 rpm)
 - CO ≤0.2%



Figure 3.20 Exhaust gas measuring components (Source: Bosch Media)



Figure 3.21 Exhaust gas measuring system in use (Source: Bosch Media)

Table 3.8 European past and future emission limits

Emissions standard	Particulate matters (PM)/ (mg/km)		Oxides of nitrogen (NO_x) (mg/km)		Hydrocarbons (HC) (mg/km)	
	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol
Euro 2 (1996)	80–100	–	–	–	–	–
Euro 3 (2000)	50	–	500	150	–	200
Euro 4 (2005)	25	–	250	80	–	100
Euro 5 (2009)	5	5	180	70	–	100
Euro 6 (2014)	5	5	80	70	–	100

 - HC ≤200 ppm
 - Lambda 0.97–1.03
- Idle (450–1500 rpm)
 - CO ≤0.3%

Manufacturers, however, have to meet stringent regulations when producing new vehicles. In Europe, the emission standards are def ned in a series of EU directives staging the progressive introduction of increasingly stringent standards (Table 3.8).

In the United States, Tier 2 standards are divided into several numbered 'bins' (Table 3.9). Eleven bins were initially def ned, with bin 1 being the cleanest (zero emission vehicle) and 11 the dirtiest. However, bins 9, 10 and 11 are temporary. Only the f rst 10 bins were used for light-duty vehicles below 8500 pounds gross vehicle weight rating (GVWR), but medium-duty passenger vehicles up to 10 000 pounds (4536 kg) GVWR used all 11 bins. Manufacturers can make vehicles which f t into any of the available bins, but still must meet average targets for their entire f eets.

The two least-restrictive bins, 9 and 10, for passenger cars phased out at the end of 2006. However, bins 9 and 10 were available for classifying a restricted number of light-duty trucks until the end of 2008, when they were removed along with bin 11 for medium-duty vehicles. As of 2009, light-duty trucks must meet the same emissions standards as passenger cars.

Phase 2 was from 2004 to 2009, and now even more stringent standards are coming into use. Also, the California Air Resources Board (CARB) may adopt and enforce its own emissions standards. However, regardless of whether a manufacturer receives CARB approval, all new motor vehicles and engines must still receive certif cation from the environmental protection agency (EPA) before a vehicle is introduced.

3.5 Pressure testing

3.5.1 Introduction

Measuring the fuel pressure on fuel injection engine is of great value when fault f nding. Many types of pressure testers are available and they often come as part of a kit consisting of various adapters and connections (Figure 3.22). The principle of mechanical gauges is that they contain a very small tube wound in

Table 3.9 Tier 2 exhaust emission standards (United States)

	Standard	Emission limits at 50 000 miles					Emission limits at full useful life (120 000 miles)[a]				
		NO_x (g/mi)	NMOG (g/mi)	CO (g/mi)	PM (g/mi)	HCHO (g/mi)	NO_x (g/mi)	NMOG (g/mi)	CO (g/mi)	PM (g/mi)	HCHO (g/mi)
Federal	Bin 1	–	–	–	–	–	0	0	0	0	0
	Bin 2	–	–	–	–	–	0.02	0.01	2.1	0.01	0.004
	Bin 3	–	–	–	–	–	0.03	0.055	2.1	0.01	0.011
	Bin 4	–	–	–	–	–	0.04	0.07	2.1	0.01	0.011
	Bin 5	0.05	0.075	3.4	–	0.015	0.07	0.09	4.2	0.01	0.018
	Bin 6	0.08	0.075	3.4	–	0.015	0.1	0.09	4.2	0.01	0.018
	Bin 7	0.11	0.075	3.4	–	0.015	0.15	0.09	4.2	0.02	0.018
	Bin 8	0.14	0.100/0.125[c]	3.4	–	0.015	0.2	0.125/0.156	4.2	0.02	0.018
	Bin 9[b]	0.2	0.075/0.140	3.4	–	0.015	0.3	0.090/0.180	4.2	0.06	0.018
	Bin 10[b]	0.4	0.125/0.160	3.4/4.4	–	0.015/0.018	0.6	0.156/0.230[c]	4.2/6.4	0.08	0.018/0.027
	Bin 11[b]	0.6	0.195	5	–	0.022	0.9	0.28	7.3	0.12	0.032

[a] In lieu of intermediate useful life standards (50 000 miles) or to gain additional NO_x credit, manufacturers may optionally certify to the Tier 2 exhaust emission standards with a useful life of 150 000 miles.
[b] Bins 9–11 expire in 2006 for light-duty vehicles and light light-duty trucks and in 2008 for heavy light-duty trucks and all heavy passenger vehicles.
[c] Pollutants with two numbers have a separate certification standard (first number) and in-use standard (second number).
NMOG – non-methane organic gases.
HCHO – formaldehyde.



Figure 3.22 Fuel pressure gauge kit



Figure 3.23 Compression tester



Figure 3.24 Automotive pressure transducer (Source: PicoTech)

Def nition

Transducer: A device that converts a physical quantity (e.g. force, torque, pressure, rotation) to an electrical signal.

a spiral. As f uid or gas under pressure is forced into the spiral tube, it unwinds causing a needle to move over a graduated scale.

Measuring engine cylinder compression or leakage is a useful test. Figure 3.23 shows an engine compression tester. This device is used to compare cylinder compressions as well as to measure actual values.

3.5.2 Automotive pressure oscilloscope transducer

PicoTech has developed an accurate pressure transducer (Figure 3.24) that can be used for pressure analysis of many automotive systems.

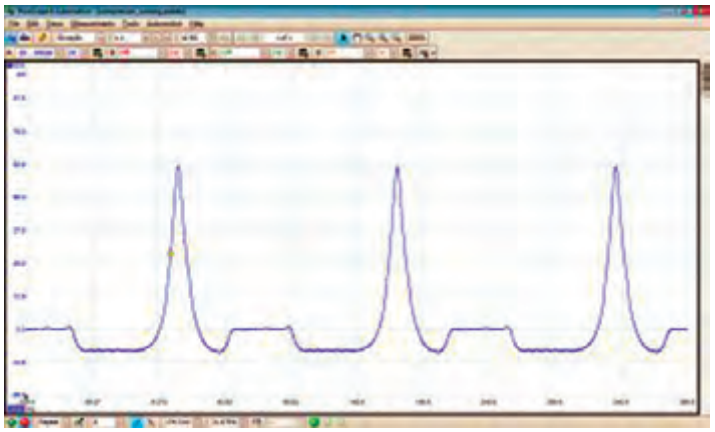


Figure 3.25 Running compression waveform

Some of the key features are as follows:

- range accurate from 0.07 psi (5 mbar) to 500 psi (34.5 bar);
- 100 µs response time;
- zoom function for enhanced analysis;
- temperature compensation.

These result in an accurate representation of rapidly changing signals that span across a broad pressure range.

The three pressure ranges of the device allow for accurate measurement and analysis of many automotive pressures, including

- cylinder compression;
- fuel pressure;
- intake manifold vacuum;
- pulses from the exhaust.

The first range gives high resolution and accuracy for high-pressure tests such as cranking and running cylinder compression or fuel pressure testing.

The second range measures from −15 to 50 psi (approximately −1 to 3.45 bar). This range is ideal for vacuum tests and fuel system tests. The zoom function is especially useful on these tests as it makes it easy to analyse the valves operating with the vacuum waveform, or the injectors through the fuel waveform (Figure 3.25).

With the third range you can measure −5 to 5 psi (approximately −0.34 to 0.34 bar). This setting is sensitive enough to allow analysis of small pressures or pulses such as from the exhaust. This is an excellent way of checking even for running cylinders.

CHAPTER

Sensors, actuators and oscilloscope diagnostics

4.1 Introduction

The issues and diagnostic techniques used for sensors and actuators are common to many systems. For example, the testing procedure for an inductive engine speed sensor on a fuel injection system is the same as for an inductive speed sensor on an antilock brake system (ABS) system. Testing sensors to diagnose faults is usually a matter of measuring their output signal. In some cases, the sensor will produce this on its own (e.g. an inductive sensor). In other cases, it will be necessary to supply the correct voltage to the device to make it work (e.g. Hall sensor). It is normal to check that the vehicle circuit is supplying the voltage before proceeding to test the sensor.

Key fact

Testing sensors to diagnose faults is usually a matter of measuring their output signal.

At the beginning of the sections on sensors and actuators, a table is included listing the device, equipment, test method(s), results of the tests and, in most cases, a reference to a scope waveform. A waveform is often the recommended method of testing. The waveform shown will either be the output of a sensor or the signal supplied to an actuator.

Note: Any f gures given are average or typical values. Refer to a good reference source such as a workshop manual or 'data book' for specif c values.

Author's Note: The waveforms in this chapter were captured using the PicoScope® automotive oscilloscope. I am most grateful to the PicoTech team for supplying information and equipment to assist in the production of this chapter (http://www.picoscope.com).

4.2 Sensors

4.2.1 Introduction and sensor diagnostics

A sensor is a device that measures a physical quantity and converts it into a signal which can be read by an electronic control unit (ECU), an observer or an instrument. For accuracy, most sensors are calibrated against known standards. Most vehicle sensors produce an electrical signal, so checking their output on an oscilloscope is often the recommended method. However, many can also be checked using a multimeter (Table 4.1).

Key fact

Most vehicle sensors produce an electrical signal.

Advanced Automotive Fault Diagnosis.
© 2012 Tom Denton. Published by Routledge. All rights reserved.

Table 4.1 Sensor diagnostic methods

Sensor	Equipment	Method(s)	Results	Scope waveform
Thermistor Coolant sensor Air intake temperature sensor Ambient temperature sensor Etc.	Ohmmeter	Connect across the two terminals, or if only one, from this to earth	Most thermistors have a negative temperature coefficient (NTC). This means the resistance falls as temperature rises. A resistance check should give readings broadly as follows: 0 °C = 4500 Ω 20 °C = 1200 Ω 100 °C = 200 Ω	Figure 4.14
Inductive Crankshaft speed and position ABS wheel speed Camshaft position	Ohmmeter AC voltmeter	A resistance test with the sensor disconnected AC voltage output with the engine cranking	Values vary from approx. 200–400 Ω on some vehicles to 800–1200 Ω on others. The 'sine wave' output should be approx. 5 V (less depending on engine speed)	Figure 4.2 Figure 4.4 Figure 4.7
Hall effect Ignition distributor Engine speed Transmission speed Wheel speed Current flow in a wire (ammeter amp clamp)	DC voltmeter Logic probe Do NOT use an ohmmeter as this will damage the Hall chip	The voltage output measured as the engine or component is rotated slowly. The sensor is normally supplied with a 5 V or a 10–12 V	This distributor switches between 0 and approx. 8 as the Hall chip is magnetised or not. Others switch between 0 and approx. 4 V A logic probe will read high and low as the sensor output switches	Figure 4.3 Figure 4.17 Figure 4.19
Optical Ignition distributor Rotational speed	DC voltmeter	The device will normally be supplied with a stabilised voltage. Check the output wire signal as the device is rotated slowly	Clear switching between low and high voltage	N/A
Variable resistance Throttle potentiometer Flap-type airflow sensor Position sensor	DC voltmeter Ohmmeter	This sensor is a variable resistor. If the supply is left connected then check the output on a DC voltmeter With the supply disconnected, check the resistance	The voltage should change *smoothly* from approx. 0 to the supply voltage (often 5V) Resistance should change smoothly	Figure 4.8 Figure 4.10
Strain gauges MAP sensor Torque stress	DC voltmeter	The normal supply to an externally mounted manifold absolute pressure (MAP) sensor is 5V. Check the output as manifold pressure changes either by snapping the throttle open, road testing or by using a vacuum pump on the sensor pipe	The output should change between approx. 0 and 5 V as the manifold pressure changes. As a general guide 2.5 V at idle speed	N/A

(*Continued*)

Table 4.1 (Continued)

Sensor	Equipment	Method(s)	Results	Scope waveform
Variable capacitance	DC voltmeter	Measure the voltage at the sensor	Small changes as the input to the sensor is varied – this is nc diff cult to assess because of very low capacitance values	N/A
Accelerometer Knock sensors	Scope	Tap the engine block lightly (13mm spanner) near the sensor	Oscillating output that drops back to zero If the*whole* system is operating, the engine will slow down if at idle speed	Figure 4.21
Hot wire Airf ow	DC voltmeter or duty cycle meter	This sensor includes electronic circuits to condition the signal from the hot wire. The normal supply is either 5 or 12V. Measure the output voltage as engine speed/load is varied	The output should change between approx. 0 and V5 as the airf ow changes 0.4–1 V at idle is typical. Or depending on the system in use the output may be digital	Figure 4.12
Oxygen Lambda sensor EGO sensor HEGO sensor	DC voltmeter	The lambda sensor produces its own voltage a bit like a battery. This can be measured with the sensor connected to the system	A voltage of approx. 450mV (0.45 V) is the normalgure produced at lambda value of one The voltage output, however should vary smoothly between 0.2 and 0.8V as the mixture is controlled by the ECU	Figure 4.24 Figure 4.26 Figure 4.27
Acceleration switch Dynamic position	DC voltmeter	Measure the supply and output as the sensor is subjected to the required acceleration	A clear switching between say 0 and 12V	N/A
Rain and other unknown types	DC voltmeter	Locate output wire – by trial and error if necessary and measure dry/wet output (splash water on the screen with the sensor correctly f tted in position)	A clear switching between distinct voltage levels	N/A

4.2.2 Inductive sensors

Inductive-type sensors are used mostly for measuring the speed and position of a rotating component. They work on the very basic principle of electrical induction (a changing magnetic f ux will induce an electromotive force in a winding). The output voltage of most inductive-type sensors approximates to a sine wave. The amplitude of this signal depends on the rate of change of f ux. This is determined mostly by the original design as in the number of turns,

Key fact

The amplitude of an inductive sensor signal depends on the rate of change of f ux.



Figure 4.1 Crank sensor in position near the engine flywheel

magnet strength and gap between the sensor and the rotating component. Once in use, though, the output voltage increases with the speed of rotation. In the majority of applications, it is the frequency of the signal that is used.

4.2.2.1 Crankshaft and camshaft sensors

Inductive-type crank and cam sensors work in the same way. A single tooth, or toothed wheel, induces a voltage into a winding in the sensor. The cam sensor provides engine position information as well as which cylinder is on which stroke. The crank sensor provides engine speed. It also provides engine position in many cases by use of a 'missing' tooth (Figure 4.1).

In this particular waveform, we can evaluate the output voltage from the crank sensor. The voltage will differ between manufacturers, and it also increases with engine speed. The waveform will be an alternating voltage signal.

If there is a gap in the trace, it is due to a 'missing tooth' on the flywheel or reluctor and is used as a reference for the ECU to determine the engine's position. Some systems use two reference points per revolution (Figure 4.2).

Definition

CID: Cylinder identification.

The camshaft sensor is sometimes referred to as the cylinder identification (CID) sensor or a 'phase' sensor and is used as a reference to time sequential fuel injection.

The voltage produced by the camshaft sensor will be determined by several factors, these being the engine's speed, the proximity of the metal rotor to the pick-up and the strength of the magnetic field offered by the sensor. The ECU needs to see the signal when the engine is started for its reference; if absent, it can alter the point at which the fuel is injected. The driver of the vehicle may not be aware that the vehicle has a problem if the CID sensor fails, as the drivability may not be affected. However, the MIL should illuminate.

The characteristics of a good inductive camshaft sensor waveform is a sine wave that increases in magnitude as the engine speed is increased, and usually provides one signal per 720° of crankshaft rotation (360° of camshaft rotation).

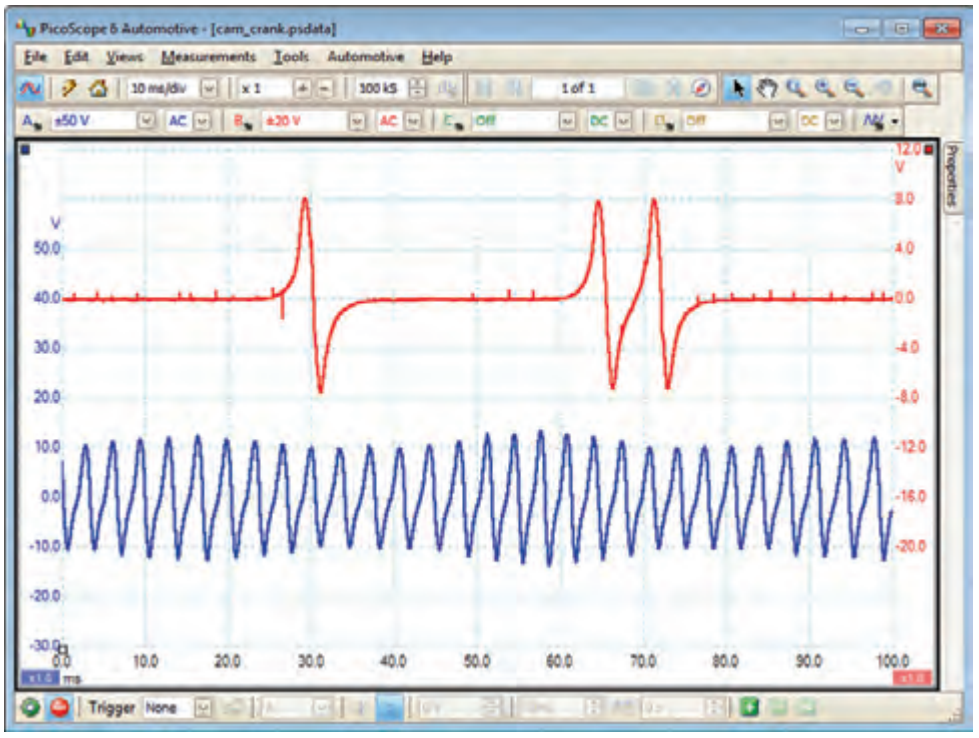


Figure 4.2 Crank and cam sensor output signals

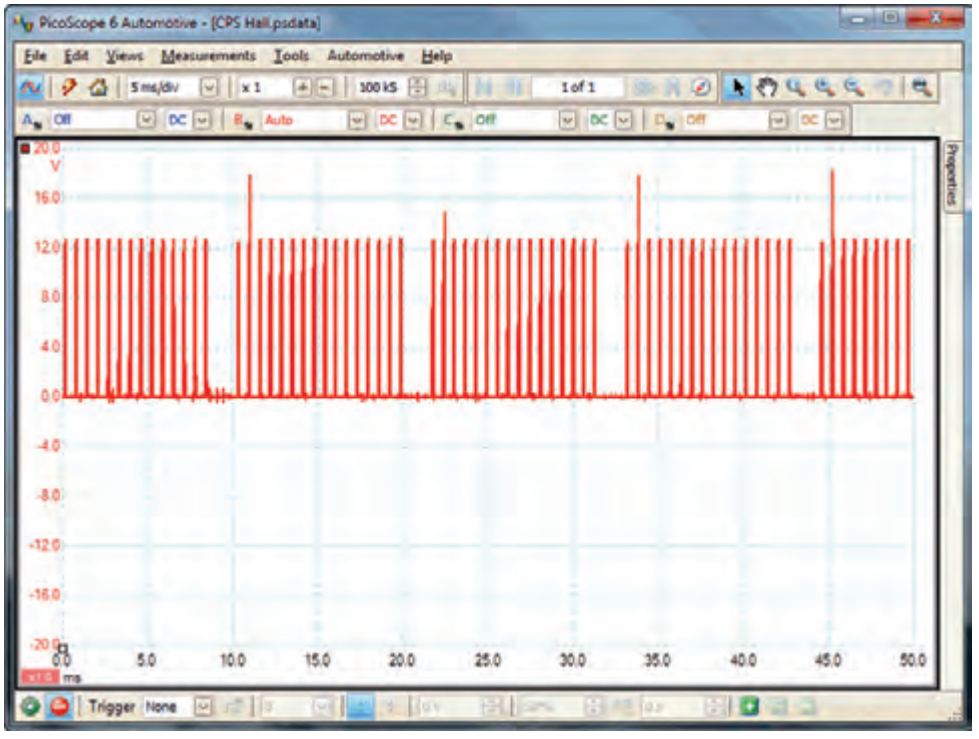


Figure 4.3 Hall effect crank sensor

The voltage will be approximately 0.5 V peak to peak while the engine is cranking, rising to around 2.5 V peak to peak at idle.

Some crankshaft sensors (CAS) are now Hall effect types and will therefore show a broadly square wave signal (Figure 4.3).



Figure 4.4 ABS wheel speed sensors (Source: Bosch Press)

4.2.2.2 ABS speed sensor

The ABS wheel speed sensors have become smaller and more eff cient in the course of time. Recent models not only measure the speed and direction of wheel rotation but can be integrated into the wheel bearing as well (Figure 4.4).

ABS relies upon information coming in from the sensors to determine what action should be taken. If, under heavy braking, the ABS ECU loses a signal from one of the road wheels, it assumes that the wheel has locked and releases that brake momentarily until it sees the signal return. It is therefore imperative that the sensors are capable of providing a signal to the ABS ECU. If the signal produced from one wheel sensor is at a lower frequency than the others, the ECU may also react (Figures 4.5 and 4.6).

The operation of most ABS sensors is similar to that of a crank angle sensor (CAS). A small inductive pick-up is affected by the movement of a toothed wheel, which moves in close proximity. The movement of the wheel next to the sensor results in a 'sine wave'. The sensor, recognisable by its two electrical connections (some may have a coaxial braided outer shield), will produce an output that can be monitored and measured on the oscilloscope. Some are now Hall effect types so expect to see a square wave output.

Def nition

CAS: Crank angle sensor

4.2.2.3 Inductive distributor pick-up

Not used on modern cars, but there are still plenty out there! The pick-up is used as a signal to trigger the ignition amplif er or an ECU. The sensor normally has two connections. If a third connection is used, it is normally a screen to reduce interference.

As a metal rotor spins, a magnetic f eld is altered, which induces an AC voltage from the pick-up. This type of pick-up could be described as a small alternator because the output voltage rises as the metal rotor approaches the winding,

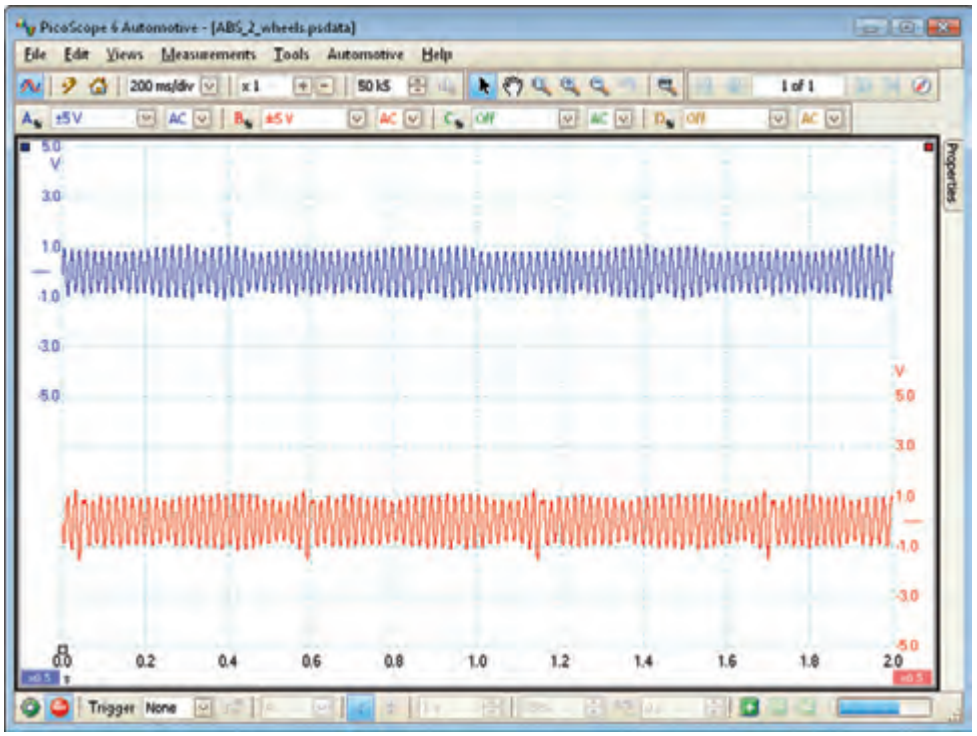


Figure 4.5 ABS speed sensor waveform

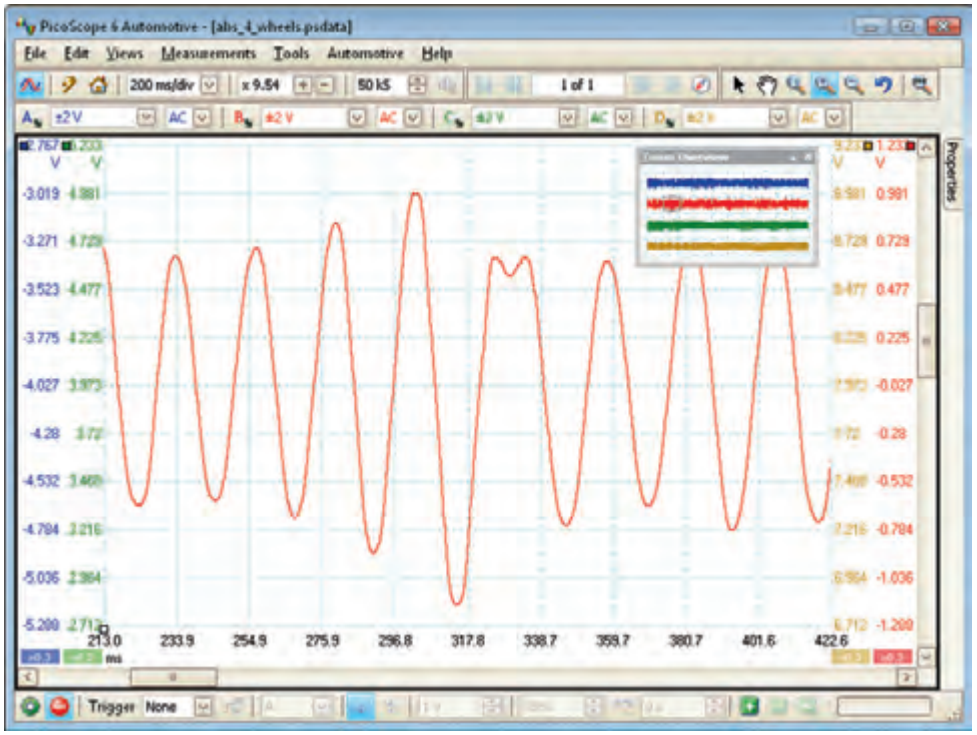


Figure 4.6 ABS speed sensor waveform zoomed in to show the effect of a broken tooth

sharply dropping through zero volts as the two components are aligned and producing a voltage in the opposite direction as the rotor passes. The waveform is similar to a sine wave; however, the design of the components is such that a more rapid switching is evident (Figure 4.7).

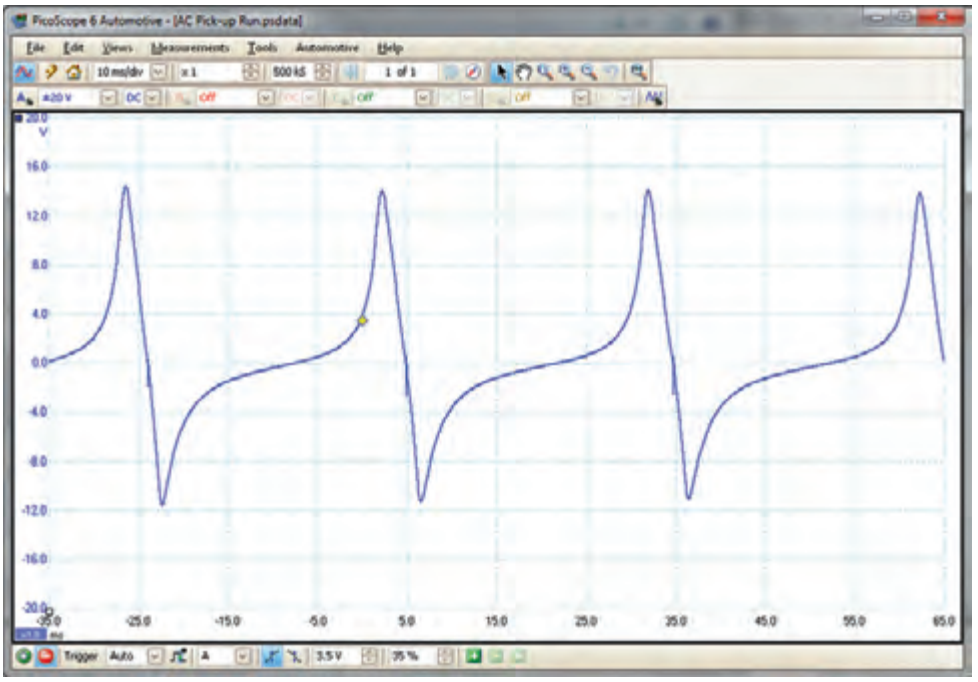


Figure 4.7 Inductive pick-up output signal (engine running)

The voltage produced by the pick-up will be determined by three main factors:

- Engine speed – the voltage produced will rise from as low as 2–3 V when cranking, to over 50 V at higher engine speeds.
- The proximity of the metal rotor to the pick-up winding – an average air gap will be in the order of 0.2–0.6 mm (8–14 thou), a larger air gap will reduce the strength of the magnetic f eld seen by the winding and the output voltage will be reduced.
- The strength of the magnetic f eld offered by the magnet – the strength of this magnetic f eld determines the effect it has as it 'cuts' through the windings, and the output voltage will be reduced accordingly.

A difference between the positive and the negative voltages may also be apparent as the negative side of the sine wave is sometimes attenuated (reduced) when connected to the amplif er circuit, but will produce perfect AC when disconnected and tested under cranking conditions.

4.2.3 Variable resistance

The two best examples of vehicle applications for variable resistance sensors are the throttle position sensor and the f ap-type airf ow sensor. Although variable capacitance sensors are used to measure small changes, variable resistance sensors generally measure larger changes in position. This is due to lack of sensitivity inherent in the construction of the resistive track. The throttle position sensor is a potentiometer in which, when supplied with a stable voltage, often 5 V, the voltage from the wiper contact will be proportional to throttle position. The throttle potentiometer is mostly used to indicate rate of change of throttle position. This information is used when implementing acceleration enrichment or overrun fuel cut-off. The output voltage of a rotary potentiometer is proportional to its position.

Key fact

Variable capacitance sensors are used to measure small changes; variable resistance sensors generally measure larger changes in position.

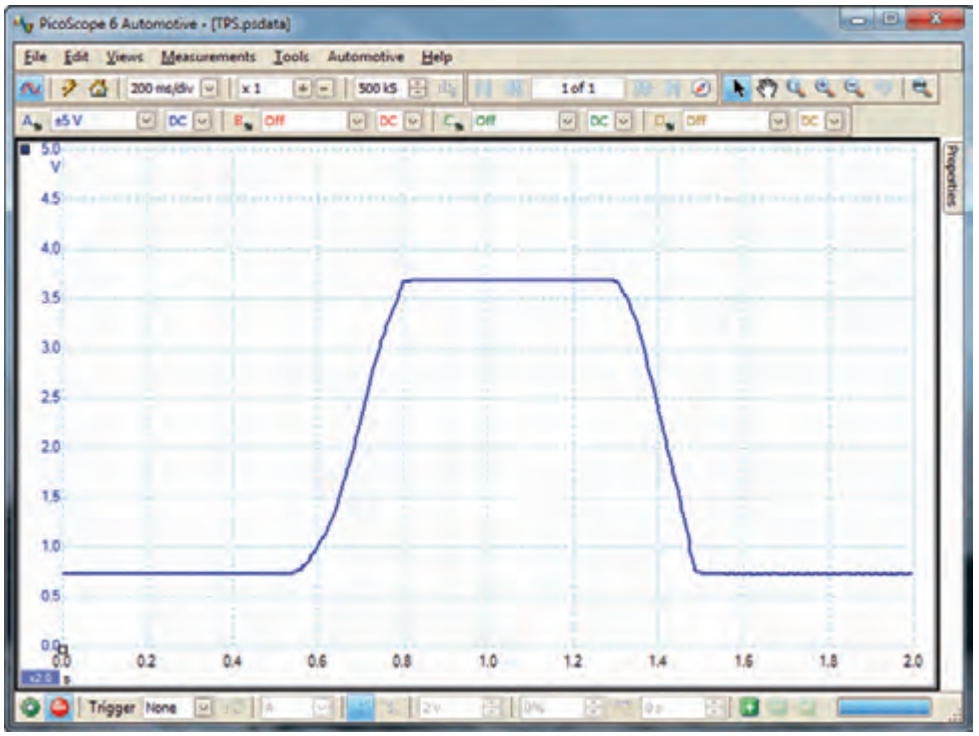


Figure 4.8 Throttle pot output voltage

The airf ow sensor shown in Figure 4.9 works on the principle of measuring the force exerted on the f ap by the air passing through it. A calibrated coil spring exerts a counter force on the f ap such that the movement of the f ap is proportional to the volume of air passing through the sensor. To reduce the f uctuations caused by individual induction strokes, a compensation f ap is connected to the sensor f ap. The f uctuations therefore affect both f aps and are cancelled out. Any damage due to back f ring is also minimised due to this design. The resistive material used for the track is a ceramic metal mixture, which is burnt into a ceramic plate at very high temperature. The slider potentiometer is calibrated such that the output voltage is proportional to the quantity of inducted air. This sensor type is not used on modern vehicles as more accurate measurement is possible using other techniques.

4.2.3.1 Throttle position potentiometer

This sensor or potentiometer is able to indicate to the ECU the exact amount of throttle opening due to its linear output.

The majority of modern management systems use this type of sensor. It is located on the throttle butterf y spindle. The ‘throttle pot’ is a three-wire device having a 5 V supply (usually), an earth connection and a variable output from the centre pin. As the output is critical to the vehicle’s performance, any ‘blind spots’ within the internal carbon track’s swept area, will cause ‘f at spots’ and ‘hesitations’. This lack of continuity can be seen on an oscilloscope (Figure 4.8).

A good throttle potentiometer should show a small voltage at the throttle closed position, gradually rising in voltage as the throttle is opened and returning back to its initial voltage as the throttle is closed. Although many throttle position sensor voltages will be manufacturer specif c, many are non-adjustable and the voltage will be in the region of 0.5–1.0 V at idle, rising to 4.0 V (or more) with a

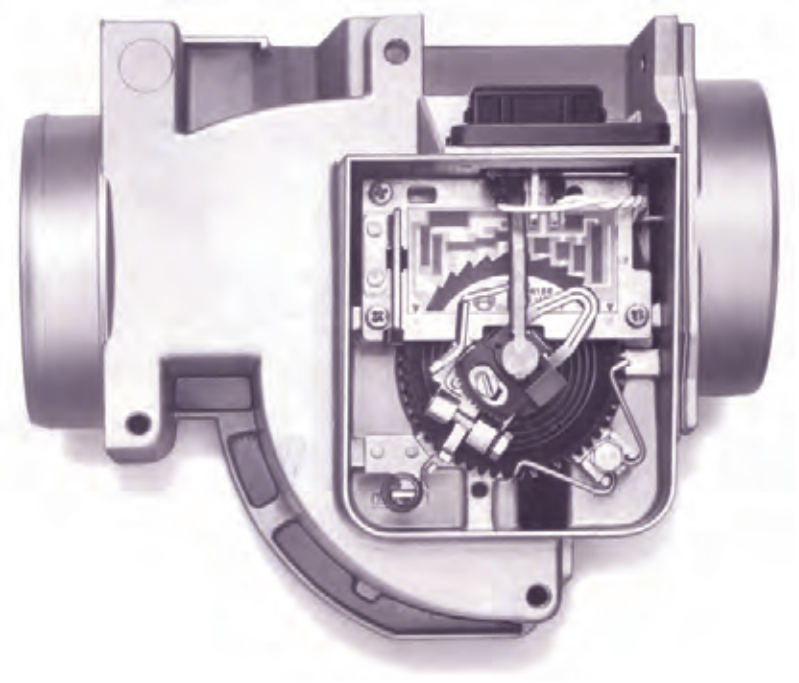


Figure 4.9 Vane- or flap-type airflow sensor (Source: Bosch)

fully opened throttle. For the full operational range, an oscilloscope time scale around two seconds is used.

4.2.3.2 Airflow meter – air vane

The vane-type airflow meter is a simple potentiometer that produces a voltage output that is proportional to the position of a vane. The vane in turn positions itself proportional to the amount of air flowing (Figure 4.9).

The voltage output from the internal track of the airflow meter should be linear to flap movement; this can be measured on an oscilloscope and should look similar to the example shown in Figure 4.10.

The waveform should show approximately 1.0 V when the engine is at idle; this voltage will rise as the engine is accelerated and will produce an initial peak. This peak is due to the natural inertia of the air vane and drops momentarily before the voltage is seen to rise again to a peak of approximately 4.0–4.5 V. This voltage will, however, depend on how hard the engine is accelerated, so a lower voltage is not necessarily a fault within the airflow meter. On deceleration, the voltage will drop sharply as the wiper arm, in contact with the carbon track, returns back to the idle position. This voltage may in some cases 'dip' below the initial voltage before returning to idle voltage. A gradual drop will be seen on an engine fitted with an idle speed control valve (ISCV) as this will slowly return the engine back to base idle as an anti-stall characteristic.

A time base of approximately two seconds plus is used; this enables the movement to be shown on one screen, from idle through acceleration and back to idle again. The waveform should be clean with no 'drop-out' in the voltage, as this indicates a lack of electrical continuity. This is common on an airflow meter with a dirty or faulty carbon track. The problem will appear as a 'flat spot' or hesitation when the vehicle is driven, this is a typical problem on vehicles with high mileage that have spent the majority of their working life with the throttle in one position.

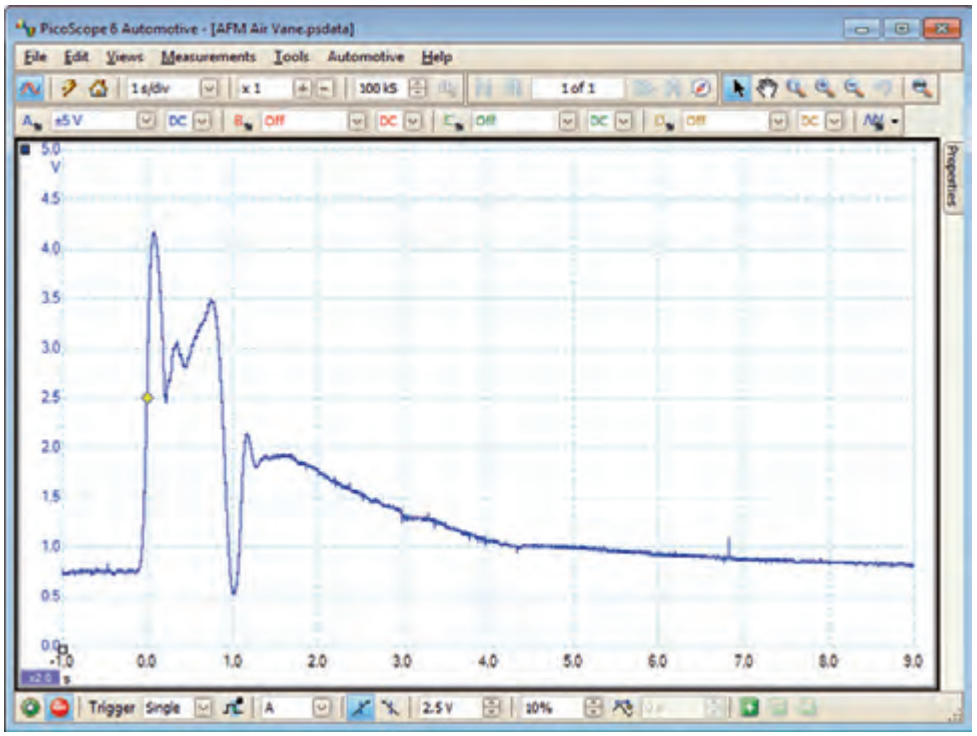


Figure 4.10 Air vane output voltage

4.2.4 Hot wire airf ow sensor

The advantage of this sensor is that it measures air mass f ow. The basic principle is that as air passes over a hot wire, it tries to cool the wire down. If a circuit is created such as to increase the current through the wire, then this current will be proportional to the airf ow. A resistor is also incorporated to compensate for temperature variations. The 'hot wire' is made of platinum and is only a few millimetres long and approximately 70 µm thick. Because of its small size, the time constant of the sensor is very short, in fact in the order of a few milliseconds. This is a great advantage as any pulsations of the airf ow will be detected and reacted to in a control unit accordingly.

The output of the circuit involved with the hot wire sensor is a voltage across a precision resistor. The resistance of the hot wire and the precision resistor are such that the current to heat the wire varies between 0.5 and 1.2 A with different air mass f ow rates. High-resistance resistors are used in the other arm of the bridge and so current f ow is very small. The temperature-compensating resistor has a resistance of approximately 500 Ω, which must remain constant other than by way of temperature change. A platinum f lm resistor is used for these reasons. The compensation resistor can cause the system to react to temperature changes within about three seconds.

The output of this device can change if the hot wire becomes dirty. Heating the wire to a very high temperature for one second every time the engine is switched off prevents this, by burning off any contamination. In some air mass sensors, a variable resistor is provided to set idle mixture. The nickel f lm airf ow sensor is similar to the hot wire system. Instead of a hot platinum wire, a thin f lm of nickel is used. The response time of this system is even shorter than the hot wire. The advantage which makes a nickel thick-f lm thermistor ideal for inlet air

Key fact

A nickel thick-film thermistor is ideal for inlet air temperature sensing because of its very short time constant.



Figure 4.11 Hot wire air mass meter (Source: Bosch Press)

temperature sensing is its very short time constant. In other words, its resistance varies very quickly with a change in air temperature.

4.2.4.1 Airf ow meter – hot wire

Figure 4.11 shows a mass airf ow sensor from Bosch. This type has been in use since 1996. As air f ows over the hot wire, it cools it down, and this produces the output signal. The sensor measures air mass because the air temperature is taken into account due to its cooling effect on the wire.

The voltage output should be linear to airf ow. This can be measured on an oscilloscope and should look similar to the example shown in Figure 4.12. The waveform should show approximately 1.0 V when the engine is at idle. This voltage will rise as the engine is accelerated and air volume is increased producing an initial peak. This peak is due to the initial inf ux of air and drops momentarily before the voltage is seen to rise again to another peak of approximately 4.0–4.5 V. This voltage will, however, depend on how hard the engine is accelerated; a lower voltage is not necessarily a fault within the meter.

On deceleration, the voltage will drop sharply as the throttle butterf y closes, reducing the airf ow, and the engine returns back to idle. The f nal voltage will drop gradually on an engine f tted with ISCV as this will slowly return the engine back to base idle as an anti-stall characteristic. This function normally only effects the engine speed from around 1200 rpm back to the idle setting.

A time base of approximately two seconds plus is used because this allows the output voltage on one screen, from idle through acceleration and back to idle again. The ‘hash’ on the waveform is due to airf ow changes caused by the induction pulses as the engine is running.

4.2.5 Thermistors

Thermistors are the most common device used for temperature measurement on the motor vehicle. The principle of measurement is that a change in temperature

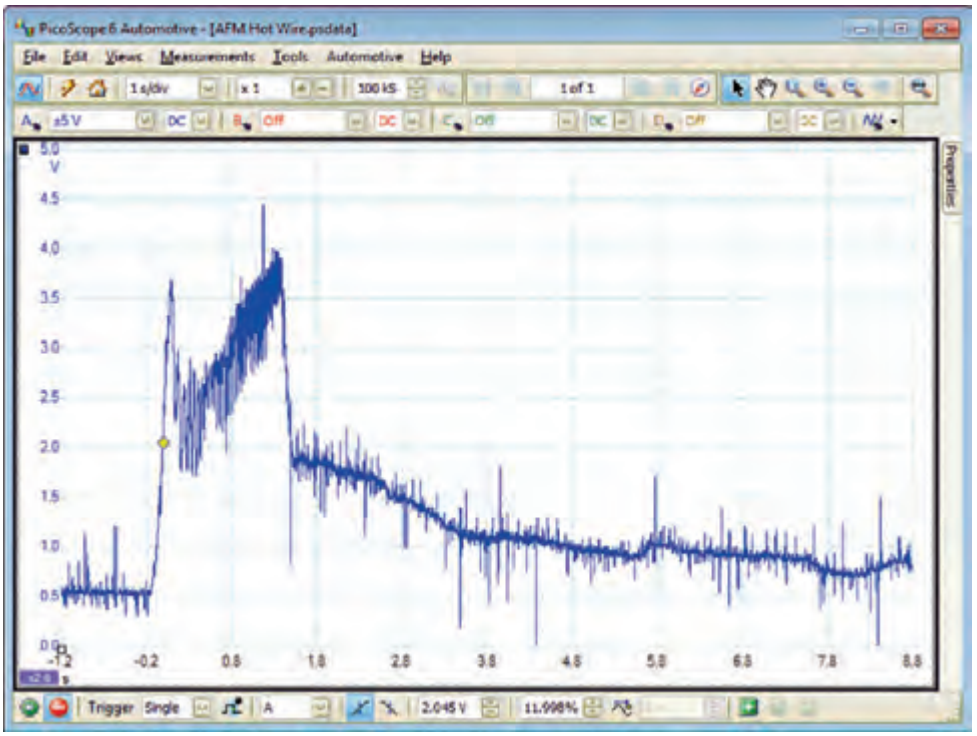


Figure 4.12 Air mass hot wire waveform



Figure 4.13 Temperature sensor

will cause a change in resistance of the thermistor and hence an electrical signal proportional to the temperature being measured. Most thermistors in common use are of the negative temperature coeff cient (NTC) type. The actual response of the thermistors can vary but typical values for those used on motor vehicles will vary from several kilo-ohms at 0 °C to few hundred ohms at 100 °C. The large change in resistance for a small change in temperature makes the thermistor ideal for most vehicles uses. It can also be easily tested with simple equipment. Thermistors are constructed of semiconductor materials. The change in resistance with a change in temperature is due to the electrons being able to break free more easily at higher temperatures.

4.2.5.1 Coolant temperature sensor

Most coolant temperature sensors (CTS) are NTC thermistors; their resistance decreases as temperature increases. This can be measured on most systems as a reducing voltage signal.

The CTS is usually a two-wire device with a voltage supply of approximately 5 V (Figure 4.13).

The resistance change will therefore alter the voltage seen at the sensor and can be monitored for any discrepancies across its operational range. By selecting a time scale of 500 seconds and connecting the oscilloscope to the sensor, the output voltage can be monitored. Start the engine and in the majority of cases the voltage will start in the region of 3–4 V and fall gradually. The voltage will depend on the temperature of the engine (Figure 4.14).

The rate of voltage change is usually linear with no sudden changes to the voltage, if the sensor displays a fault at a certain temperature, it will show up in this test.

Def nition

NTC: Negative temperature coeff cient.

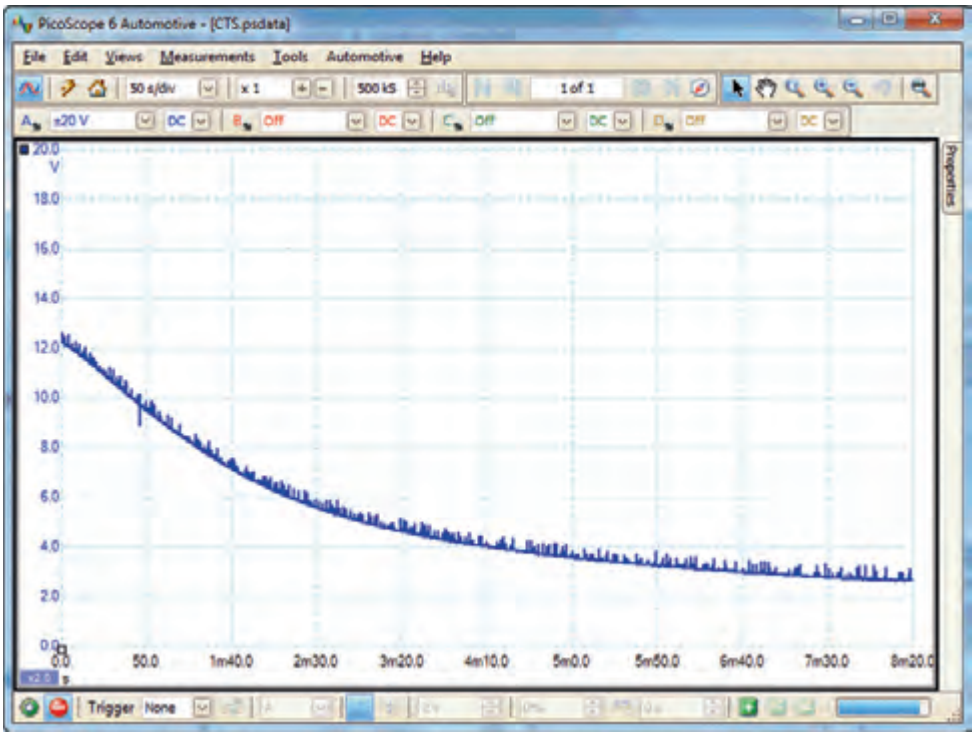


Figure 4.14 Decreasing voltage from the temperature sensor

4.2.6 Hall effect sensors

If a conductor is carrying a current in a transverse magnetic f eld, then a voltage will be produced at right angles to the supply current. This voltage is proportional to the supply current and to the magnetic f eld strength (Figure 4.15).

Many distributors employ Hall effect sensors, but they are now also used as rotational sensors for the crank and ABS, for example. The output of this sensor is almost a square wave with constant amplitude. The Hall effect can also be used to detect current f owing in a cable, the magnetic f eld produced round the cable being proportional to the current f owing. The Hall effect sensors are becoming increasingly popular because of their reliability and also because they produce a constant amplitude square wave in speed measurement applications and a varying DC voltage for either position sensing or current sensing.

The two main advantages are that measurement of lower (or even zero) speed is possible and that the voltage output of the sensors is independent of speed.

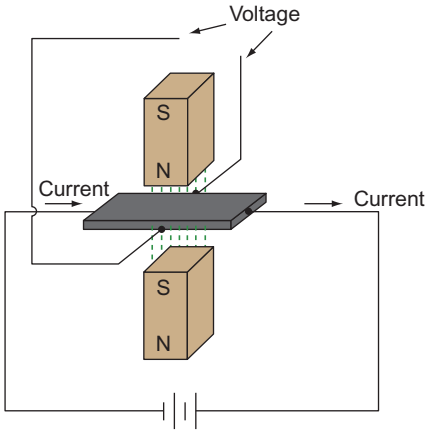


Figure 4.15 Hall effect

4.2.6.1 Hall effect distributor pick-up

Hall sensors are used in a number of ways. The ignition distributor was very common but they are not used now (Figure 4.16).

This form of trigger device is a simple digital ‘on/off switch’ which produces a square wave output that is recognised and processed by the ignition control module or engine management ECU (Figure 4.17).

The trigger has a rotating metal disc with openings that pass between an electromagnet and the semiconductor (Hall chip). This action produces a square wave that is used by the ECU or amplif er.



Figure 4.16 Distributors usually contain a Hall effect or inductive pulse generator (Source: Bosch Press)

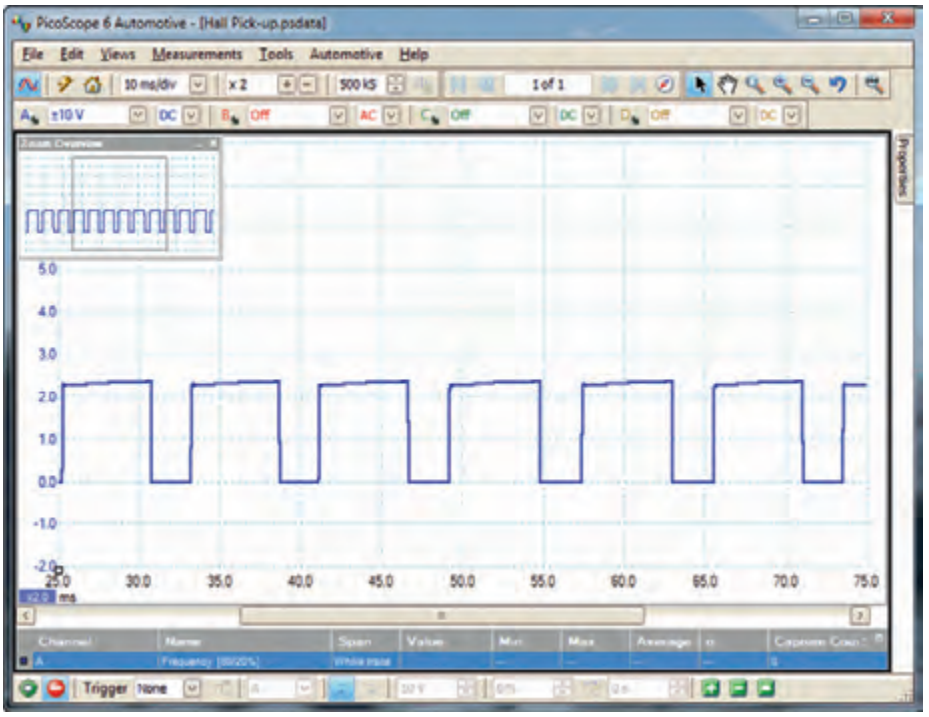


Figure 4.17 Hall output waveform

4.2.6.2 ABS Hall sensor

The sensor when used by ABS for monitoring wheel speed and as transmission speed sensors works using the same effect.

The sensor will usually have three connections: a stabilised supply voltage (often 4 or 5 V), an earth and the output signal. The square wave when monitored on an oscilloscope may vary a little in amplitude; this is not usually a problem as it is the frequency that is important. However, in most cases, the amplitude/voltage will remain constant. Table 4.2 provides a list of technical data for the sensor shown in Figure 4.18.

Table 4.2 Hall sensor data

Supply voltage	4.5 V_{DC}
Nominal sensing distance	1.5 mm
Current (typical)	10 mA
Current (max)	20 mA
Weight	30 g
Temperature range	−30 to +130 °C
Tightening torque	6 Nm
Output	PNP
Output sink voltage	0.4 V_{max}
Trigger type	Ferrous



Figure 4.18 Hall effect ABS or CAS sensor

4.2.6.3 Road speed sensor (Hall effect)

To measure the output of this sensor, jack up the driven wheels of the vehicle and place on axle stands on f rm level ground. Run the engine in gear and then probe each of the three connections (+, − and signal) (Figure 4.19).

As the road speed is increased, the frequency of the switching should be seen to increase. This change can also be measured on a multimeter with frequency capabilities. The sensor will be located on either the speedometer drive output from the gearbox or to the rear of the speedometer head if a speedo cable is used. The signal is used by the engine ECU and, if appropriate, the transmission ECU. The actual voltage will vary with sensor design.

Def nition

Piezoelectric effect: The production of electrical potential in a substance as the pressure on it changes.

4.2.7 Piezo accelerometer

A piezoelectric accelerometer is a seismic mass accelerometer using a piezoelectric crystal to convert the force on the mass due to acceleration into

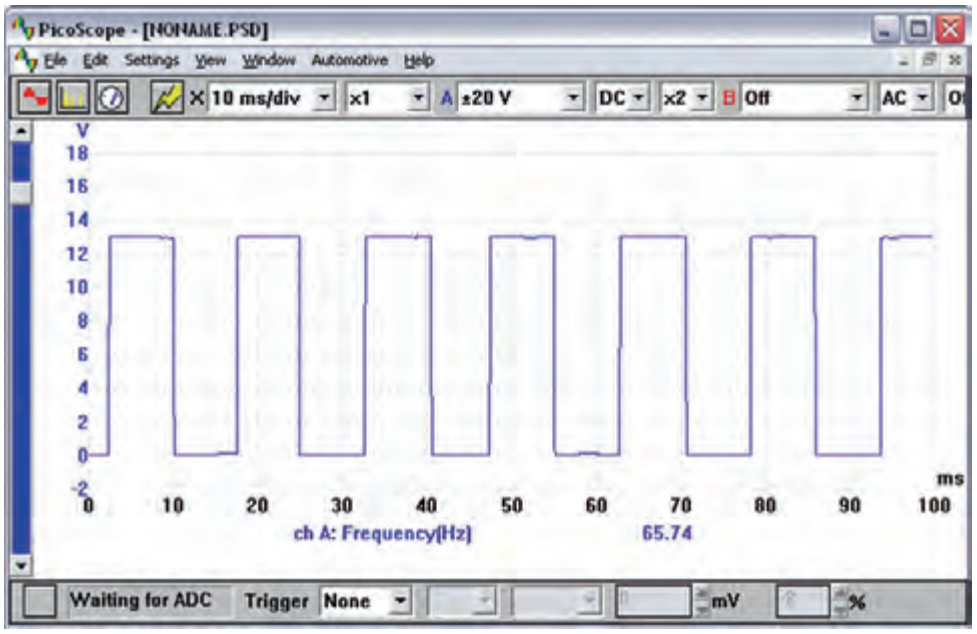


Figure 4.19 Hall effect road speed sensor waveform



Figure 4.20 Knock sensor

an electrical output signal. The crystal not only acts as the transducer but as the suspension spring for the mass. The crystal is sandwiched between the body of the sensor and the seismic mass and is kept under compression. Acceleration forces acting on the seismic mass cause variations in the amount of crystal compression and hence generate the piezoelectric voltage.

4.2.7.1 Knock sensor

The sensor, when used as an engine knock sensor, will also detect other engine vibrations. These are kept to a minimum by only looking for 'knock', a few degrees before and after top dead centre (TDC). Unwanted signals are also f ltered out electrically.

The optimal point at which the spark ignites the air/fuel mixture is just before knocking occurs. However, if the timing is set to this value, under certain conditions knock (detonation) will occur. This can cause serious engine damage as well as increase emissions and reduce eff ciency.

A knock sensor is used by some engine management systems (Figure 4.20). When coupled with the ECU, it can identify when knock occurs and retard the ignition timing accordingly.

The frequency of knocking is approximately 15 kHz. As the response of the sensor is very fast, an appropriate time scale must be set, in the case of the example waveform a 0 to 500 ms timebase and a −5 to +5 V voltage scale. The best way to test a knock sensor is to remove the knock sensor from the engine and to tap it with a small spanner – the resultant waveform should be similar to the example shown in Figure 4.21.

Note: When ref tting the sensor, tighten to the correct torque setting as overtightening can damage the sensor and/or cause it to produce incorrect signals.

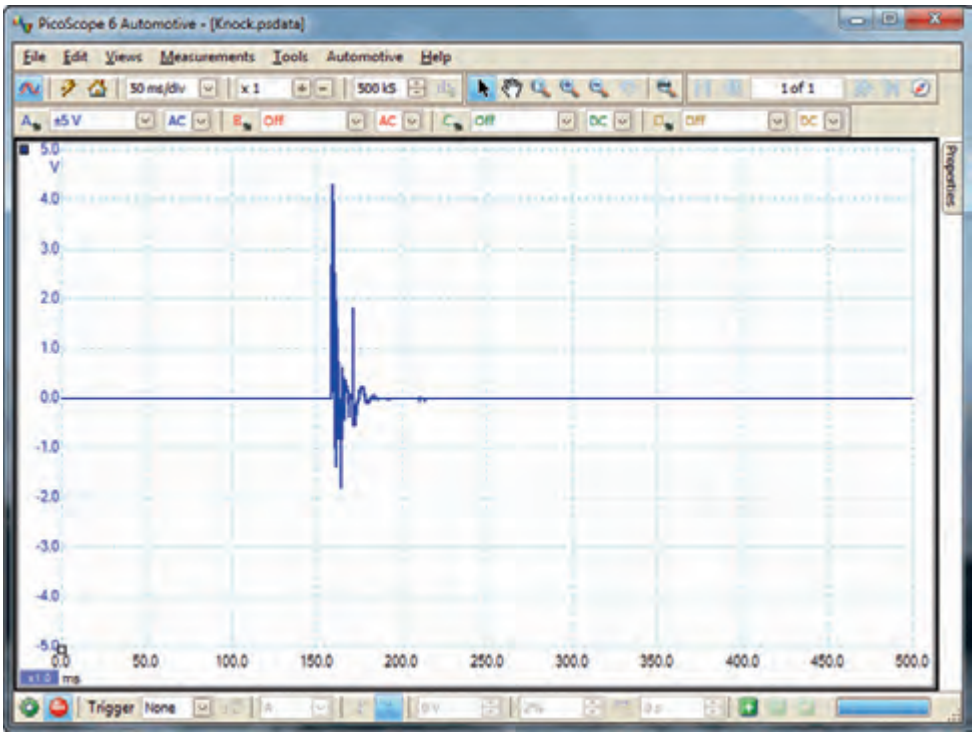


Figure 4.21 Knock sensor output signal

4.2.8 Oxygen sensors

The vehicle application for an oxygen sensor is to provide a closed loop feedback system for engine management control of the air/fuel ratio. The amount of oxygen sensed in the exhaust is directly related to the mixture strength or air/fuel ratio. The ideal air/fuel ratio of 14.7:1 by mass is known as a lambda (λ) value of 1 (Figure 4.22).

Exhaust gas oxygen (EGO) sensors are placed in the exhaust pipe near to the manifold to ensure adequate heating. The sensors operate best at temperatures over 300 °C. In some cases, a heating element is incorporated to ensure that this temperature is reached quickly. This type of sensor is known as a heated exhaust gas oxygen sensor (HEGO). The heating element (which consumes approximately 10 W) does not operate all the time to ensure that the sensor does not exceed 850 °C, at which temperature damage may occur to the sensor. This is why the sensors are not f tted directly in the exhaust manifold. The main active component of most types of oxygen sensors is zirconium dioxide (ZrO_2). This ceramic is housed in gas permeable electrodes of platinum. A further ceramic coating is applied to the side of the sensor exposed to the exhaust gas as a protection against residue from the combustion process. The principle of operation is that at temperatures in excess of 300 °C, the ZrO_2 will conduct the negative oxygen ions. The sensor is designed to be responsive very close to a lambda value of one. As one electrode of the sensor is open to a reference value of atmospheric air, a greater quantity of oxygen ions will be present on this side. Because of electrolytic action, these ions permeate the electrode and migrate through the electrolyte (ZrO_2). This builds up a charge rather like a battery.

Key fact

Most lambda sensors operate best at temperatures over 300°C.

The size of the charge is dependent on the oxygen percentage in the exhaust. The closely monitored closed loop feedback of a system using lambda sensing

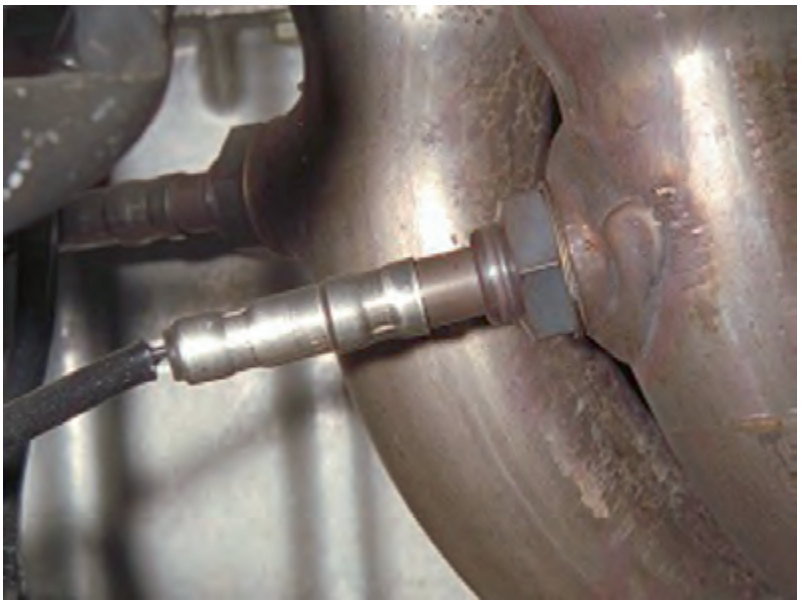


Figure 4.22 Lambda sensor in the exhaust downpipe



Figure 4.23 Titania knock sensor in position

allows very accurate control of engine fuelling. Close control of emissions is therefore possible.

4.2.8.1 Oxygen sensor (Titania)

The lambda sensor, also referred to as the oxygen sensor, plays a very important role in the control of exhaust emissions on a catalyst equipped vehicle (Figure 4.23).

The main lambda sensor is f tted into the exhaust pipe before the catalytic converter. The sensor will have four electrical connections. It reacts to the oxygen content in the exhaust system and will produce an oscillating voltage between 0.5 (lean) and 4.0 V, or above (rich) when running correctly. A second sensor to monitor the catalyst performance may be f tted downstream of the converter.

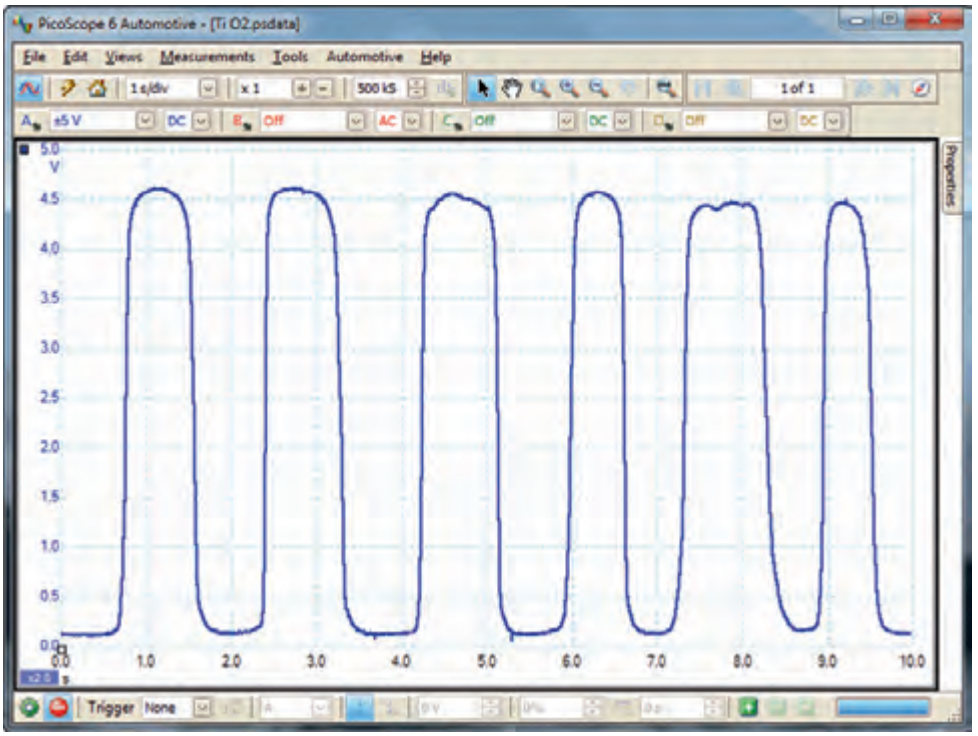


Figure 4.24 Titania lambda sensor output

Titania sensors, unlike Zirconia sensors, require a voltage supply as they do not generate their own voltage. A vehicle equipped with a lambda sensor is said to have 'closed loop', this means that after the fuel has been burnt up during the combustion process, the sensor will analyse the emissions and adjust the engine's fuelling accordingly.

Titania sensors have a heating element to assist the sensor reaching its optimum operating temperature. The sensor when working correctly will switch approximately once per second (1 Hz) but will only start to switch when at normal operating temperature. This switching can be seen on the oscilloscope, and the waveform should look similar to the one in the example (Figure 4.24).

4.2.8.2 Oxygen sensor (Zirconia)

The sensor will have varying electrical connections and may have up to four wires. It reacts to the oxygen content in the exhaust system and will produce a small voltage depending on the air/fuel mixture seen at the time. The voltage range seen will, in most cases, vary between 0.2 and 0.8 V. The 0.2 V indicates a lean mixture and a voltage of 0.8 V shows a richer mixture (Figure 4.25).

Lambda sensors can have a heating element to assist the sensor reaching its optimum operating temperature. Zirconia sensors when working correctly will switch approximately once per second (1 Hz) and will only start to switch when at normal operating temperature. This switching can be seen on the oscilloscope, and the waveform should look similar to the one in the example waveform (Figure 4.26).

Key fact

Many vehicles now have a pre- and post-cat lambda sensor

Many vehicles now have a pre- and post-cat lambda sensor. Comparing the outputs of these two sensors is a good indicator of catalyst operation and condition (Figure 4.27).



Figure 4.25 Zirconia-type oxygen sensor

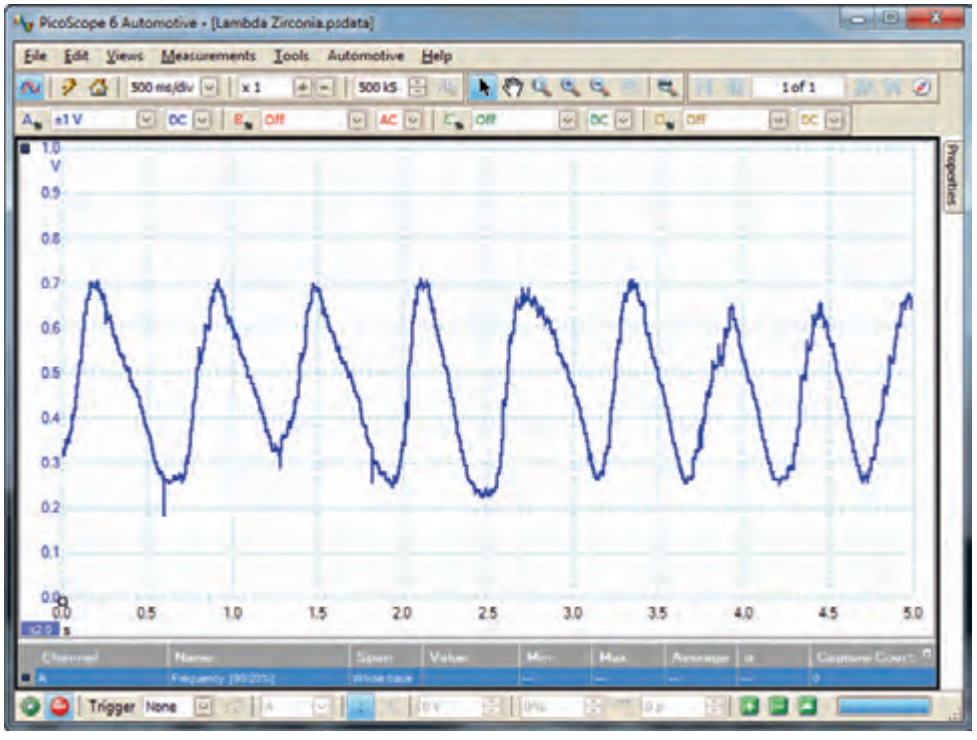


Figure 4.26 Zirconia oxygen sensor output

4.2.9 Pressure sensors

4.2.9.1 Strain gauges

When a strain gauge is stretched its resistance will increase, and when it is compressed its resistance decreases. Most strain gauges consist of a thin layer of f lm that is f xed to a f exible backing sheet. This in turn is bonded to the part where strain is to be measured. Most resistance strain gauges have a resistance of approximately 100 Ω.

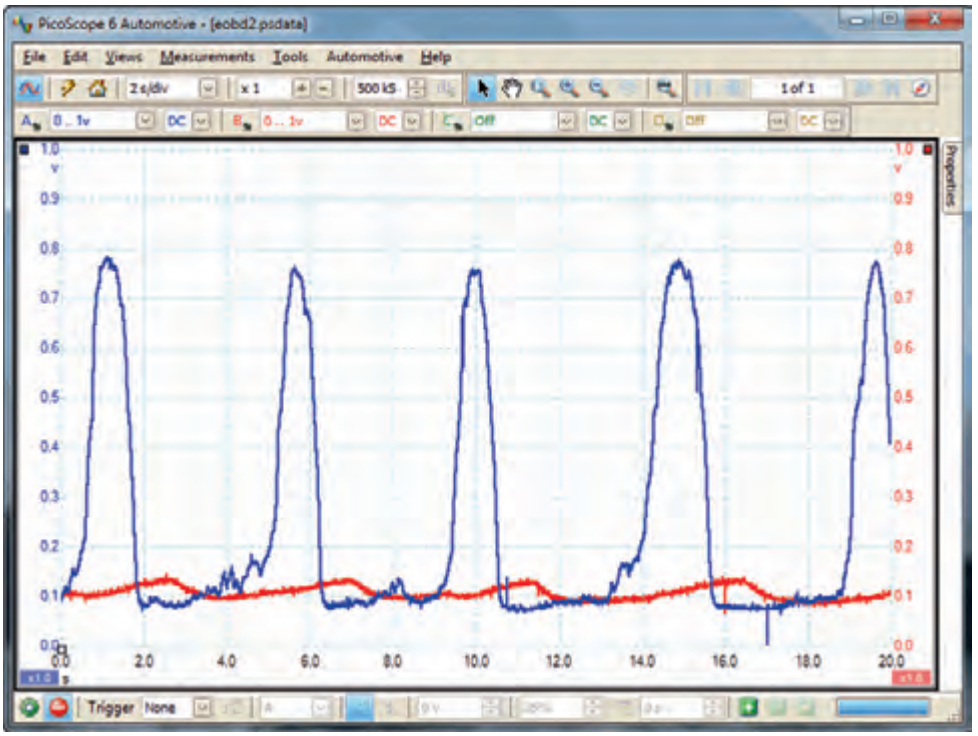


Figure 4.27 Pre-cat signal shown in blue and post-cat in red

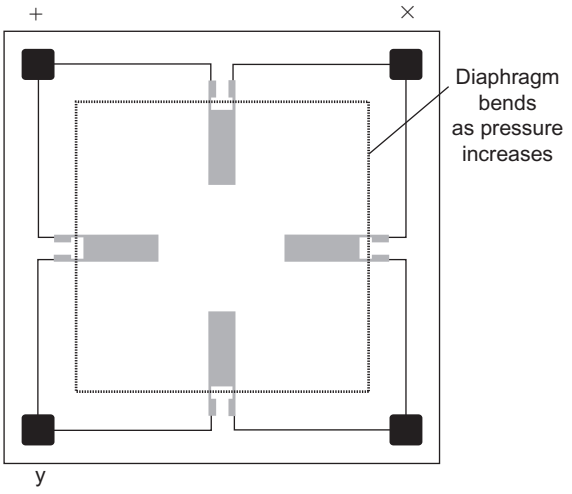


Figure 4.28 Strain gauge pressure sensor

Strain gauges are often used indirectly to measure engine manifold pressure. Figure 4.28 shows an arrangement of four strain gauges on a diaphragm forming part of an aneroid chamber used to measure pressure. When changes in manifold pressure act on the diaphragm, the gauges detect the strain. The output of the circuit is via a differential amplif er, which must have a very high input resistance so as not to affect the bridge balance. The actual size of this sensor may be only a few millimetres in diameter. Changes in temperature are compensated for by using four gauges which when affected in a similar way cancel out any changes.

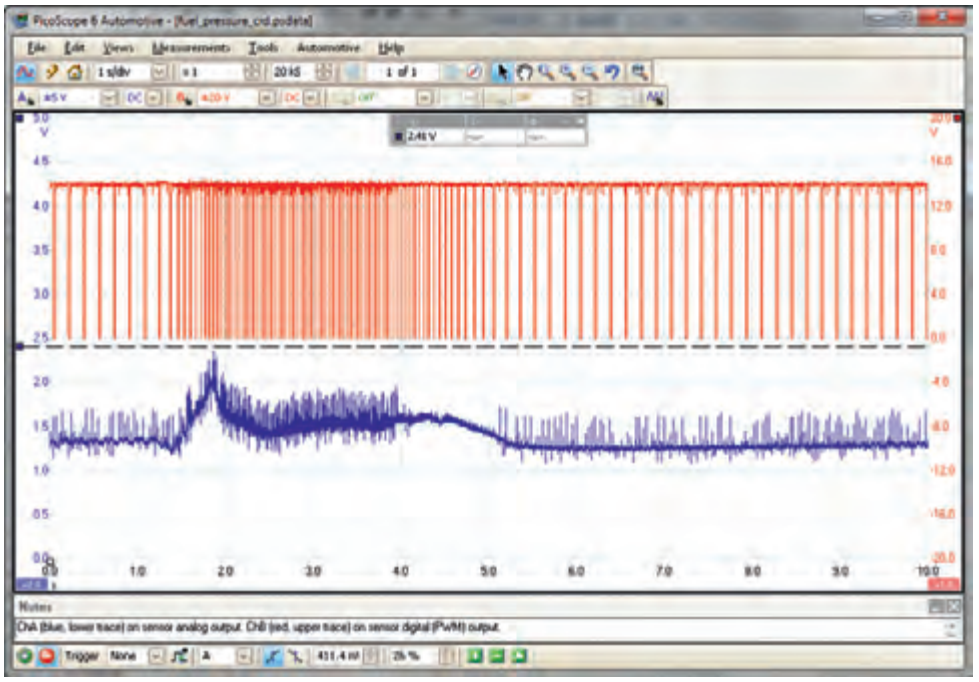


Figure 4.29 Common rail fuel pressure, the blue trace is from the sensor analogue output the red trace is from sensor digital (PWM) output

Def nition

PWM: Pulse width modulation is an adjustment of the duty cycle of a signal or power source, to either convey information over a communications channel or control the amount of power sent to a load (e.g. an actuator).

4.2.9.2 Fuel pressure

Common rail diesel system pressure signals can be tested (remember these systems operate at very high pressure). The pulse width modulation (PWM) signal should be at the same amplitude but the on/off ratio can vary (Figure 4.29).

4.2.9.3 Manifold absolute pressure

Manifold absolute pressure (MAP) is a signal used to determine engine load. There are two main types: analogue and digital. The analogue signal voltage output varies with pressure whereas the digital signal varies with frequency. These sensors use a piezo crystal, strain gauges or variable capacitance sensors or similar. The signals are also processed internally (Figures 4.30 and 4.31).

4.2.10 Variable capacitance

The value of a capacitor is determined by

- surface area of its plates;
- distance between the plates;
- the dielectric (insulation between the plates).

Sensors can be constructed to take advantage of these properties. Three sensors, each using the variable capacitance technique, are shown in Figure 4.32. These are (a) liquid level sensor in which the change in liquid level changes the dielectric value; (b) pressure sensor similar to the strain gauge pressure sensor in which the distance between capacitor plates changes; and (c) position sensor which detects changes in the area of the plates.

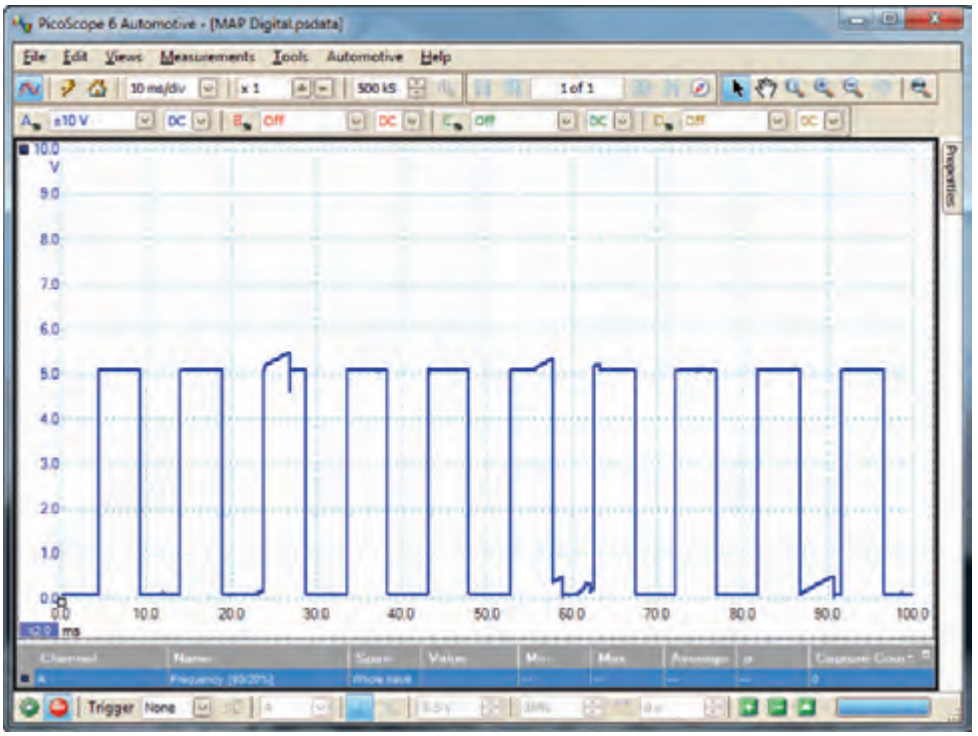


Figure 4.30 Digital MAP sensor

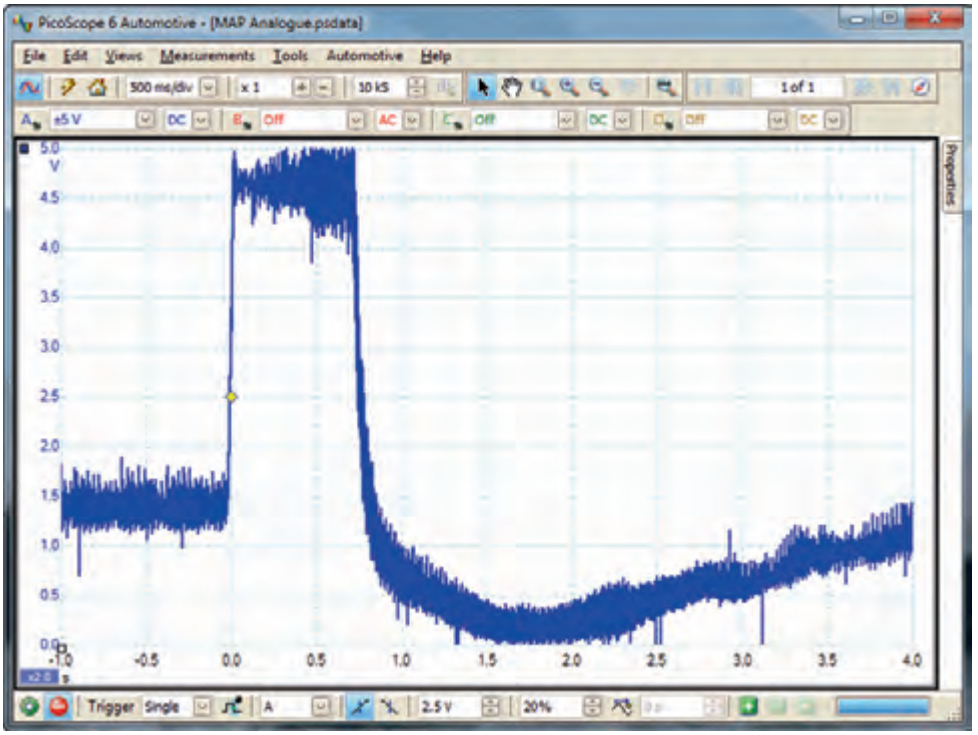


Figure 4.31 Analogue MAP sensor

4.2.10.1 Oil quality sensor

An interesting sensor used to monitor oil quality is now available, which works by monitoring changes in the dielectric constant of the oil. This value increases as antioxidant additives in the oil deplete. The value rapidly increases if coolant

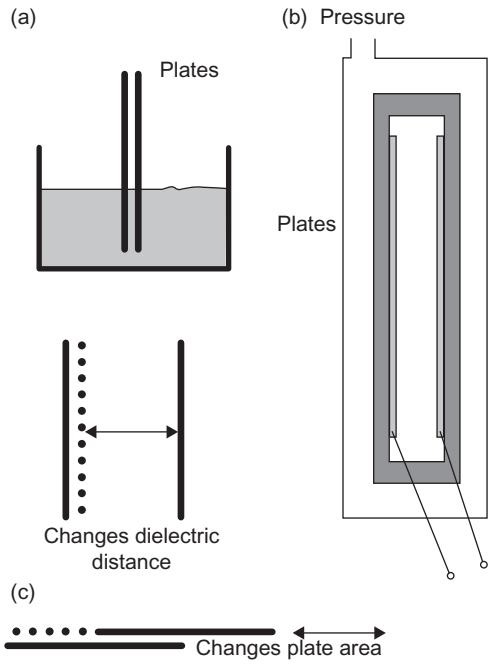


Figure 4.32 Variable capacitance sensors: (a) liquid level, (b) pressure and (c) position



Figure 4.33 Oil quality sensor (Source: Bosch Media)

contaminates the oil. The sensor output increases as the dielectric constant increases (Figure 4.33).

4.2.11 Optical sensors

An optical sensor for rotational position is a relatively simple device. The optical rotation sensor and circuit shown in Figure 4.34 consists of a phototransistor as a detector and a light emitting diode (LED) light source. If the light is focused to a very narrow beam then the output of the circuit shown will be a square wave with frequency proportional to speed.

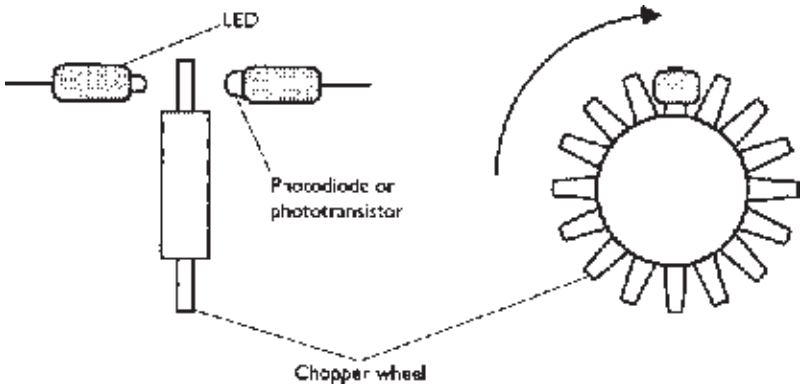


Figure 4.34 Optical sensor

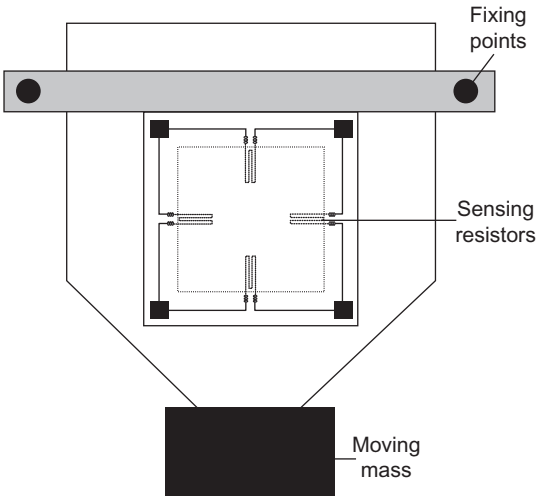


Figure 4.35 Strain gauge accelerometer

4.2.12 Dynamic position sensors

A dynamic position or movement of crash sensor can take a number of forms; these can be described as mechanical or electronic. The mechanical system works by a spring holding a roller in a set position until an impact (acceleration/deceleration) above a predetermined limit provides enough force to overcome the spring and the roller moves, triggering a micro switch. The switch is normally open with a resistor in parallel to allow the system to be monitored. Two switches similar to this may be used to ensure that an airbag is deployed only in the case of suff cient frontal impact.

Figure 4.35 is a further type of dynamic position sensor. Described as an accelerometer, it is based on strain gauges. There are two types of piezoelectric crystal accelerometer, one much like an engine knock sensor and the other using spring elements. A severe change in speed of the vehicle will cause an output from these sensors as the seismic mass moves or the springs bend. This sensor has been used by supplementary restraint systems (SRS). Warning: For safety reasons, it is not recommended to test a sensor associated with an airbag circuit without specialist knowledge and equipment.

Many sensors are now integrated into ECUs (Figure 4.36). This means that they are almost impossible to test – but fortunately have become very reliable!

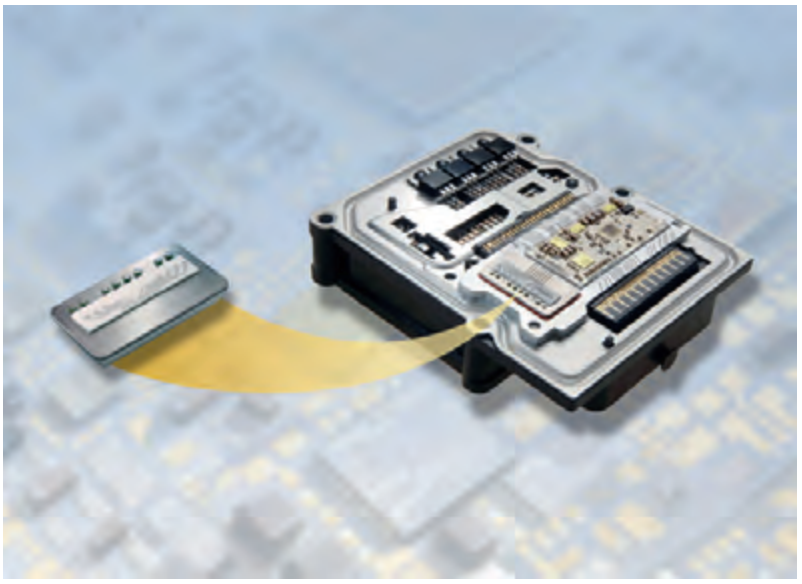


Figure 4.36 Yaw rate and acceleration sensor integrated into an electric stability program (ESP) control unit(Source: Bosch Media)

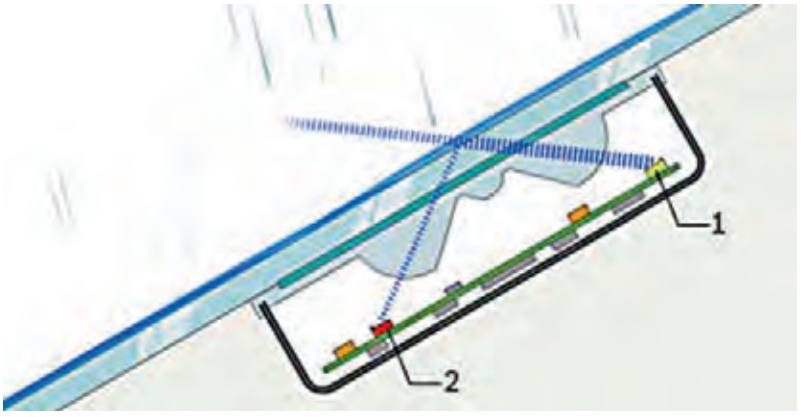


Figure 4.37 Rain sensor principle: 1 – LED; 2 – photo diode

4.2.13 Rain sensor

Rain sensors are used to switch on wipers automatically. Most work on the principle of ref ected light. The device is f tted inside the windscreen and light from an LED is ref ected back from the outer surface of the glass. The amount of light ref ected changes if the screen is wet, even with a few drops of rain (Figures 4.37 and 4.38).

4.3 Actuators

4.3.1 Introduction

There are many ways of providing control over variables in and around the vehicle. ‘Actuators’ is a general term used here to describe a control mechanism. When controlled electrically, they will work either by a thermal or by a magnetic



Figure 4.38 Rain sensor package(Source: Bosch Media)

effect. In this section, the term actuator will generally be used to mean a device which converts electrical signals into mechanical movement (Table 4.3).

4.3.2 Testing actuators

Testing actuators can be simple as many are operated by windings. The resistance can be measured with an ohmmeter. A good tip is that where an actuator has more than one winding (e.g. a stepper motor), the resistance of each should be about the same. Even if the expected value is not known, it is likely that if all the windings read the same then the device is in working order.

With some actuators, it is possible to power them up from the vehicle battery. A fuel injector should click, for example, and a rotary air bypass device should rotate about half a turn. Be careful with this method as some actuators could be damaged. At the very least, use a fused supply (jumper) wire.

Safety f rst

When powering a device, use a fused supply (jumper) wire.

4.3.3 Motorised and solenoid actuators

4.3.3.1 Motors

Permanent magnet electric motors are used in many applications and are very versatile. The output of a motor is of course rotation, and this can be used in many ways. If the motor drives a rotating 'nut' through which a plunger is f tted on which there is a screw thread, the rotary action can easily be converted to linear movement. In most vehicle applications, the output of the motor has to be geared down, this is to reduce speed and increase torque. Permanent magnet motors are almost universally used now in place of older and less practical motors with f eld windings. Some typical examples of the use of these motors are listed as follows:

- windscreen wipers;
- windscreen washers;
- headlight lift;
- electric windows;
- electric sunroof;
- electric aerial operation;
- seat adjustment;

Table 4.3 Actuator diagnostic methods

Actuator	Equipment	Method(s)	Results	Scope waveform
Solenoid Fuel injector Lock actuator	Ohmmeter	Disconnect the component and measure its resistance	The resistance of many injectors is approx. 16Ω (but check data) Lock and other actuators may have two windings (e.g. lock and unlock). The resistance values are very likely to be the same	Figures 4.47 and 4.48
Motor See previous list	Battery supply (fused) Ammeter	Most 'motor' type actuators can be run from a battery supply after they are disconnected from the circuit. If necessary the current draw can be measured	Normal operation with current draw appropriate to the 'work' done by the device. For example, a fuel pump motor may draw up to 10A, but an idle actuator will only draw 1 or 2A	N/A
Solenoid actuator (idle speed control)	Duty cycle meter	Most types are supplied with a variable ratio square wave	The duty cycle will vary as a change is required	Figure 4.41
Stepper motor Idle speed air bypass Carburettor choke control Speedometer drivers	Ohmmeter	Test the resistance of each winding with the motor disconnected from the circuit	Winding resistances should be the same. Values in the region of 10–20Ω are typical	Figure 4.44
Thermal Auxiliary air device Instrument display	Ohmmeter Fused battery supply	Check the winding for continuity; if OK, power up the device and note its operation (for instruments, power these but use a resistor in place of the sender unit)	Continuity and slow movement (several seconds to a few minutes) to close the valve or move as required	N/A
EGR valve	Ohmmeter Fused battery supply	Check the winding(s) for continuity; if OK, power up the device and note its operation	Continuity and rapid movement to close the valve	Figure 4.56

- mirror adjustment;
- headlight washers;
- headlight wipers;
- fuel pumps;
- ventilation fans.

One disadvantage of simple motor actuators is that no direct feedback of position is possible. This is not required in many applications; however, in cases such as seat adjustment when a 'memory' of the position may be needed, a variable resistor–type sensor can be fitted to provide feedback. Three typical motor actuators are shown in Figure 4.39. The two motors on the right are used for window lift. Some of these use Hall effect sensors or an extra brush as a feedback device.



Figure 4.39 Window lift and wiper motors



Figure 4.40 Rotary idle control valve

4.3.3.2 Rotary idle speed control valve

The rotary ISCV will have two or three electrical connections, with a voltage supply at battery voltage and either a single- or a double-switched earth path. The device is like a motor but only rotates about half a turn in each direction.

This device is used to control idle speed by controlling air bypass. There are two basic types in common use. These are single-winding types, which have two terminals, and double-winding types, which have three terminals. Under ECU, the motor is caused to open and close a shutter, controlling air bypass. These actuators only rotate approximately 90° to open and close the valve. As these are permanent magnet motors, the 'single or double windings' refer to the armature.

The single-winding type is fed with a square wave signal causing it to open against a spring and then close again, under spring tension. The on/off ratio or duty cycle of the square wave will determine the average valve open time and hence idle speed. With the double-winding type, the same square wave signal is sent to one winding but the inverse signal is sent to the other. As the windings are wound in opposition to each other, if the duty cycle is 50% then no movement will take place. Altering the ratio will now cause the shutter to move in one direction or the other (Figure 4.40).

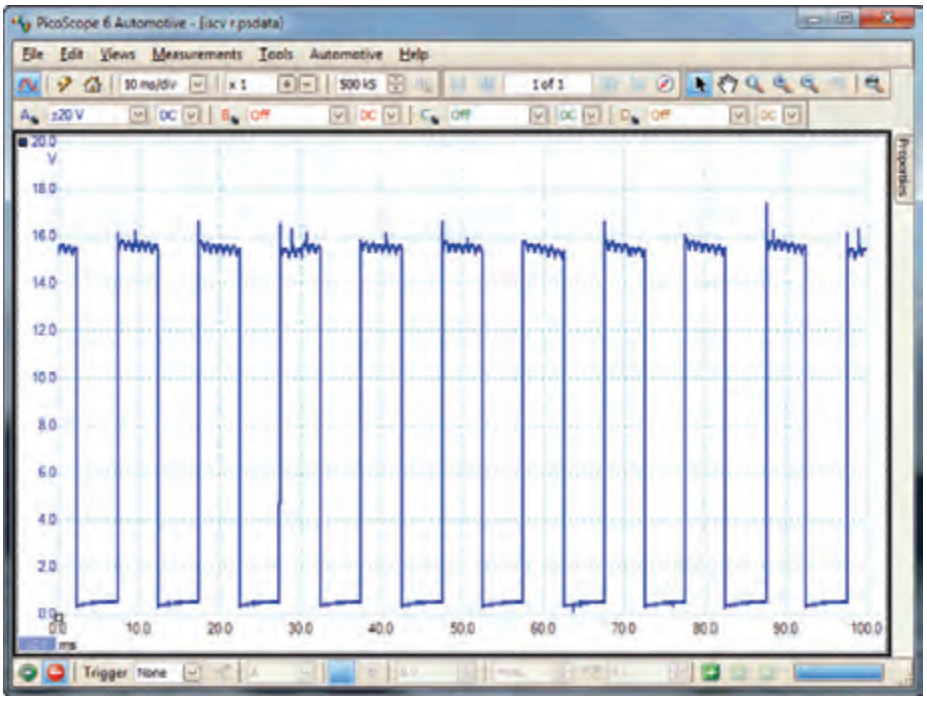


Figure 4.41 Signal supplied to a rotaryidle control valve

The rate at which the earth path is switched is determined by the ECU to maintain a prerequisite idle speed according to its programming.

The valve will form an air bypass past the throttle butterf y to form a controlled air bleed within the induction tract. The rotary valve will have the choice of either single or twin earth paths, the single being pulled one way electrically and returned to its closed position via a spring; the double-switched earth system will switch the valve in both directions. This can be monitored on a dual trace oscilloscope. As the example waveform shows, the earth path is switched and the resultant picture is produced. The idle control device takes up a position determined by the on/off ratio (duty cycle) of the supplied signal.

Probing onto the supply side will produce a straight line at system voltage, and when the earth circuit is monitored, a square wave will be seen (Figure 4.41). The frequency can also be measured as can the on/off ratio.

4.3.3.3 Stepper motors

Stepper motors are becoming increasingly popular as actuators in the motor vehicle. This is mainly because of the ease with which they can be controlled by electronic systems. Stepper motors fall into the following three distinct groups, the basic principles of which are shown in Figure 4.42:

- variable reluctance motors;
- permanent magnet (PM) motors;
- hybrid motors.

The underlying principle is the same for each type. All of them have been and are being used in various vehicle applications. The basic design for a permanent magnet stepper motor comprises two double stators. The rotor is often made of barium-ferrite in the form of a sintered annular magnet. As the windings are energised in one direction then the other, the motor will rotate in 90° steps. Half

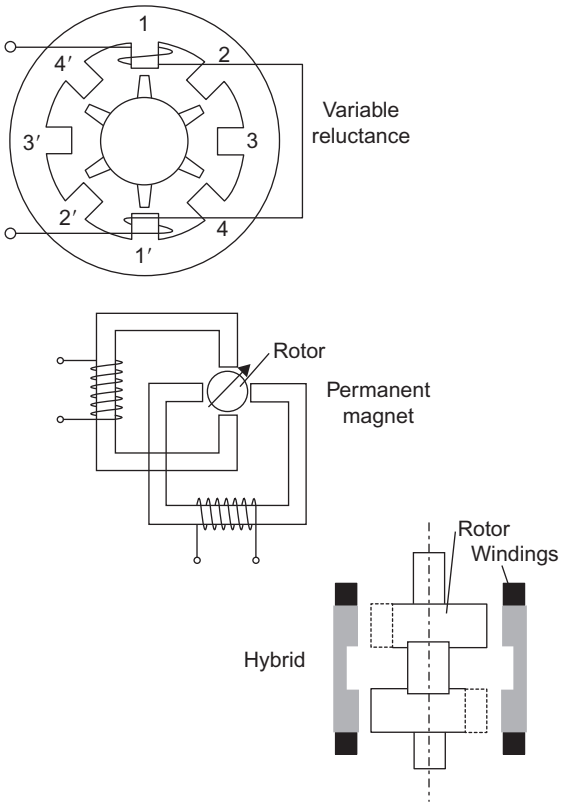


Figure 4.42 Stepper motor principle

step can be achieved by switching on two windings. This will cause the rotor to line up with the two stator poles and implement a half step of 45°. The direction of rotation is determined by the order in which the windings are switched on or off or reversed. The main advantages of a stepper motor are that feedback of position is not required. This is because the motor can be indexed to a known starting point and then a calculated number of steps will move the motor to any suitable position.

The stepper motor, when used to control idle speed, is a small electro-mechanical device that allows either an air bypass circuit or a throttle opening to alter in position depending on the amounts that the stepper is indexed (moved in known steps) (Figure 4.43).

Stepper motors are used to control the idle speed when an ISCV is not employed. The stepper may have four or f ve connections back to the ECU. These enable the control unit to move the motor in a series of 'steps' as the circuits are earthed to ground. These devices may also be used to control the position of control f aps, for example, as part of a heating and ventilation system (Figure 4.44).

The individual earth paths can be checked using the oscilloscope. The waveforms should be similar on each path. Variations to the example shown here may be seen between different systems (Figure 4.45).

4.3.4 Solenoid actuators

The basic operation of solenoid actuators is very simple. The term 'solenoid' actually means 'many coils of wire wound onto a hollow tube'. This is often misused but has become so entrenched that terms like 'starter solenoid', when really it is a starter actuator or relay, are in common use. A good example of a solenoid actuator is a fuel injector.

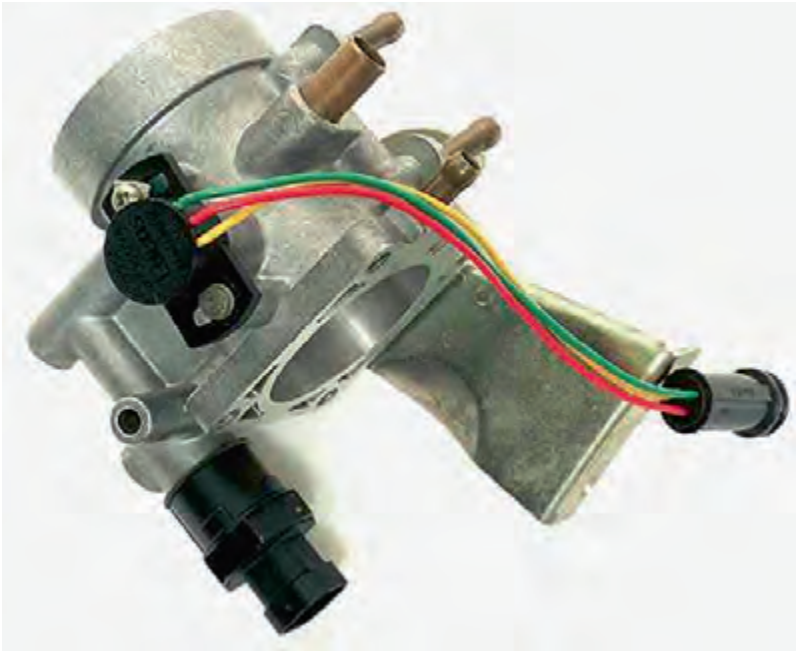


Figure 4.43 Stepper motor and throttle potentiometer on a throttle body

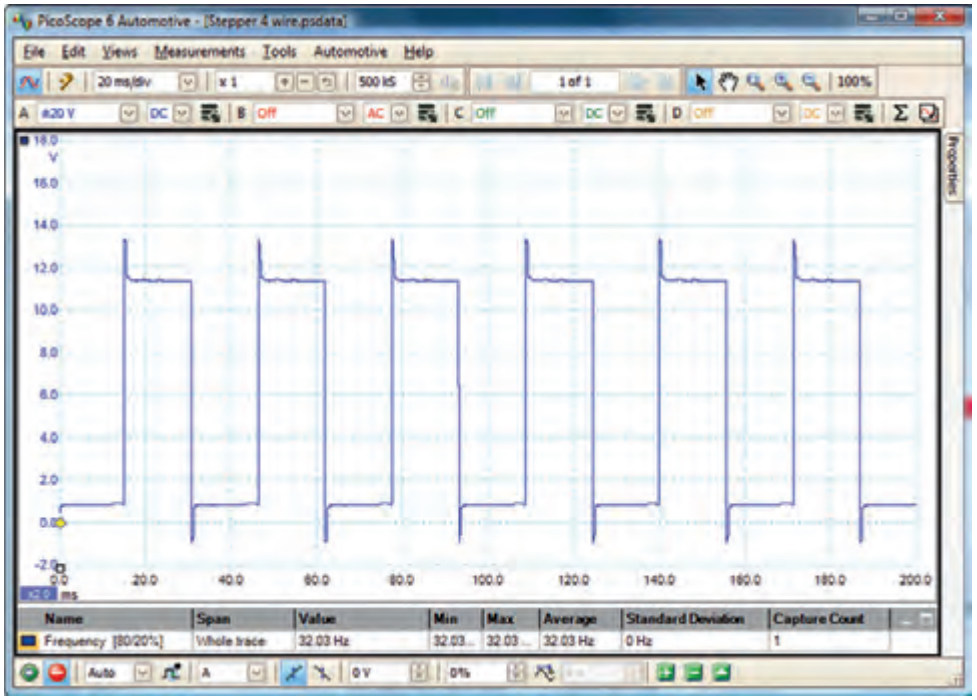


Figure 4.44 Stepper motor signals

When the windings are energised, the armature is attracted due to magnetism and compresses the spring. In the case of a fuel injector, the movement is restricted to approximately 0.1 mm. The period that an injector remains open is very small; under various operating conditions, between 1.5 and 10 ms being typical. The time it takes an injector to open and close is also critical for accurate fuel metering. Some systems use ballast resistors in series with the fuel injectors. This allows lower inductance and resistance operating windings to be used, thus speeding up reaction time.

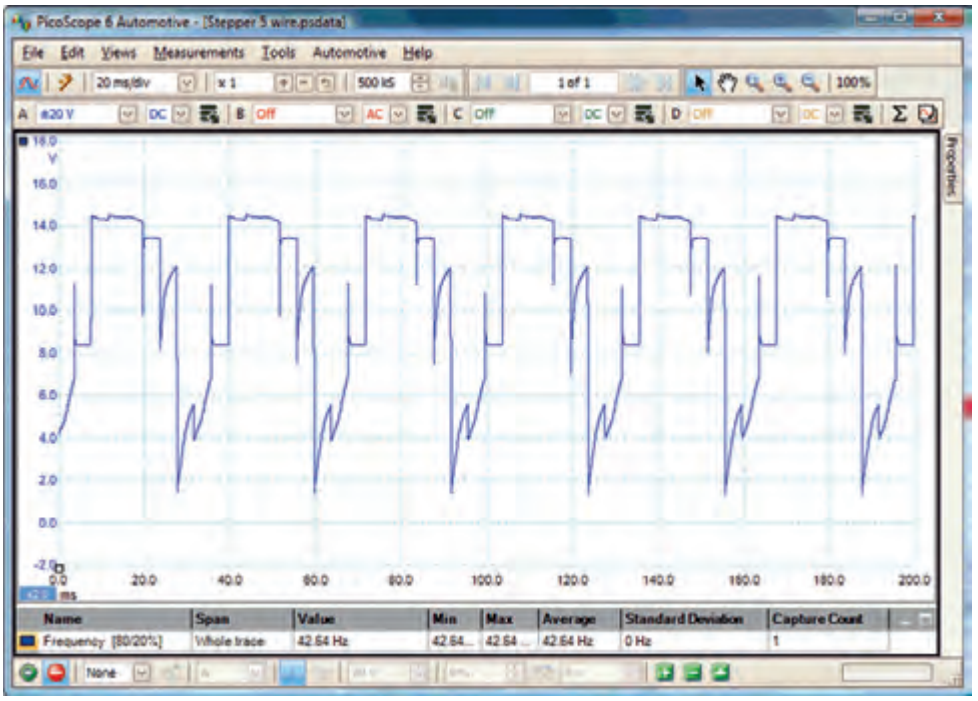


Figure 4.45 Alternative stepper motor signal

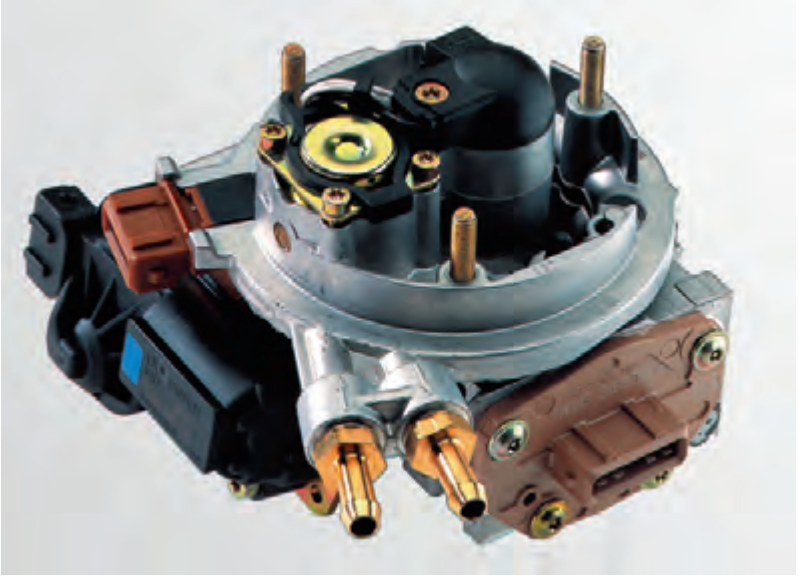


Figure 4.46 Throttle body with a single injector

Other types of solenoid actuators, for example door lock actuators, have less critical reaction times. However, the basic principle remains the same.

4.3.4.1 Single-point injector

Single-point injection is also sometimes referred to as throttle body injection (Figure 4.46).

A single injector is used (on larger engines two injectors can be used) in what may have the outward appearance to be a carburettor housing.

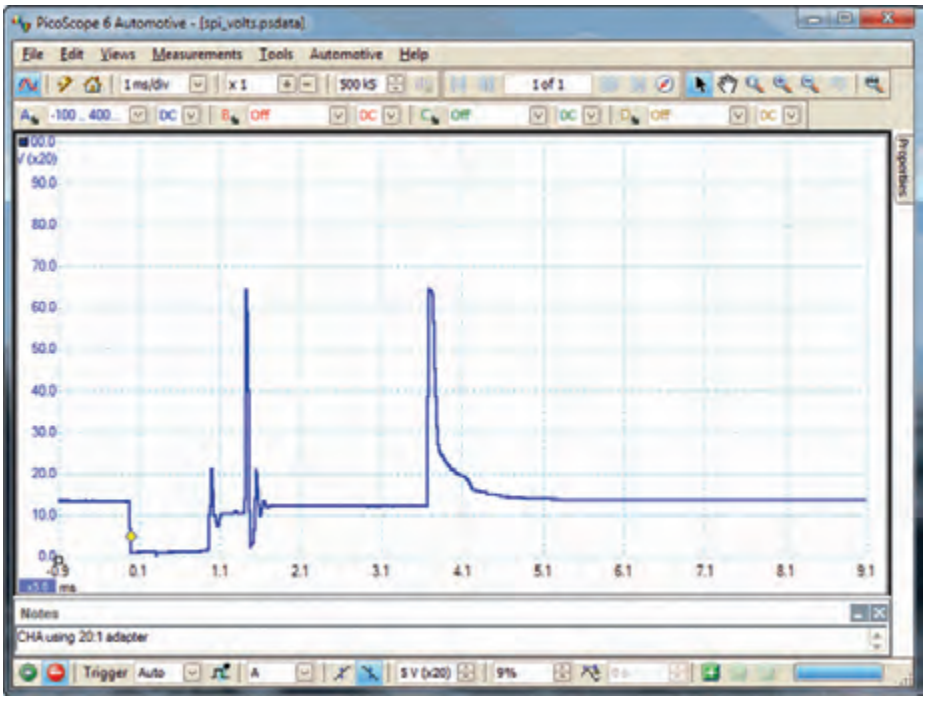


Figure 4.47 Single-point injector voltage waveform

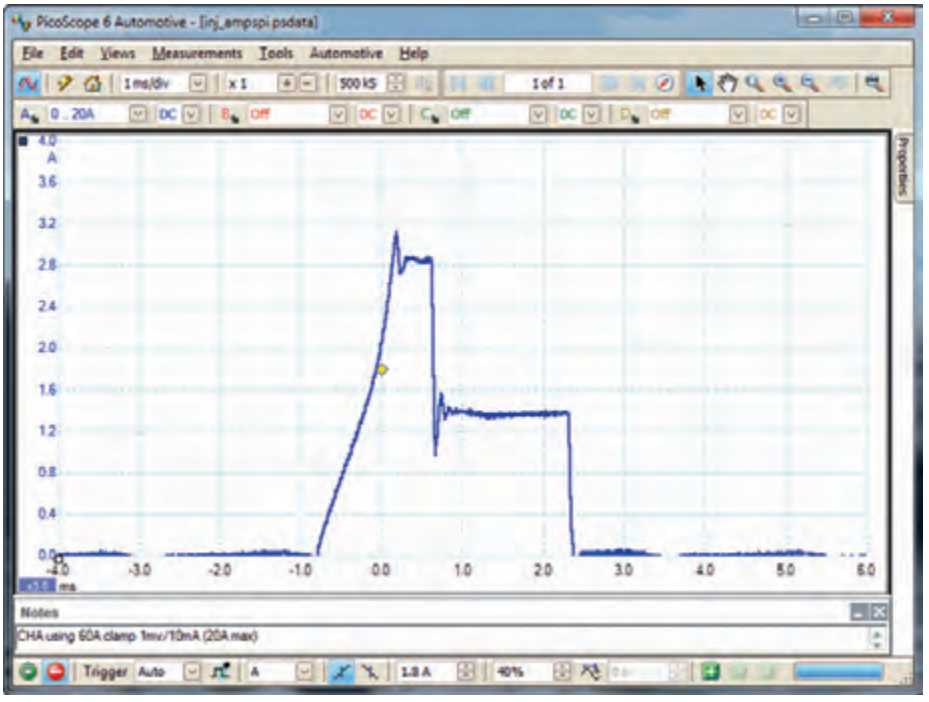


Figure 4.48 Single-point injector current waveform

The resultant waveform from the single-point system shows an initial injection period followed by voltage-pulsing of the injector in the remainder of the trace. This 'current limiting' section of the waveform is called the supplementary duration and is the part of the injection trace that expands to increase fuel quantity. This shows better in a current rather than voltage waveform (Figures 4.47 and 4.48).



Figure 4.49 Multi-point injectors on the rail. Also shown are the pressure regulator and sensor

4.3.4.2 Multi-point injector

This injector is an electro-mechanical device which is fed by a 12 V supply. The voltage will only be present when the engine is cranking or running because it is controlled by a relay that operates only when a speed signal is available from the engine. Early systems had this feature built into the relay; most modern systems control the relay from the ECU (Figure 4.49).

The length of time the injector is held open will depend on the input signals seen by the ECU from its various engine sensors. The duration of open time or 'injector duration' will vary to compensate for cold engine starting and warm-up periods. The duration time will also expand under acceleration. The injector will have a constant voltage supply while the engine is running and the earth path will be switched via the ECU, the result can be seen in the example waveform (Figure 4.50). When the earth is removed, a voltage is induced into the injector and a spike approaching 60 V is recorded.

Key fact

The length of time an injector is held open depends on the sensor input signals to the ECU.

The height of the spike will vary from vehicle to vehicle. If the value is approximately 35 V, it is because a zener diode is used in the ECU to clamp the voltage. Make sure the top of the spike is squared off, indicating the zener dumped the remainder of the spike. If it is not squared, this indicates the spike is not strong enough to make the zener fully dump, meaning there is a problem with a weak injector winding. If a zener diode is not used in the computer, the spike from a good injector will be 60 V or more.

Multi-point injection may be either sequential or simultaneous. A simultaneous system will f re all four injectors at the same time with each cylinder receiving two injection pulses per cycle (720° crankshaft rotation). A sequential system will receive just one injection pulse per cycle, which is timed to coincide with the opening of the inlet valve.

Monitoring the injector waveform using both voltage and amperage allows display of the 'correct' time that the injector is physically open. The current waveform (the one starting on the zero line) shows that the waveform is 'split' into two def ned areas.

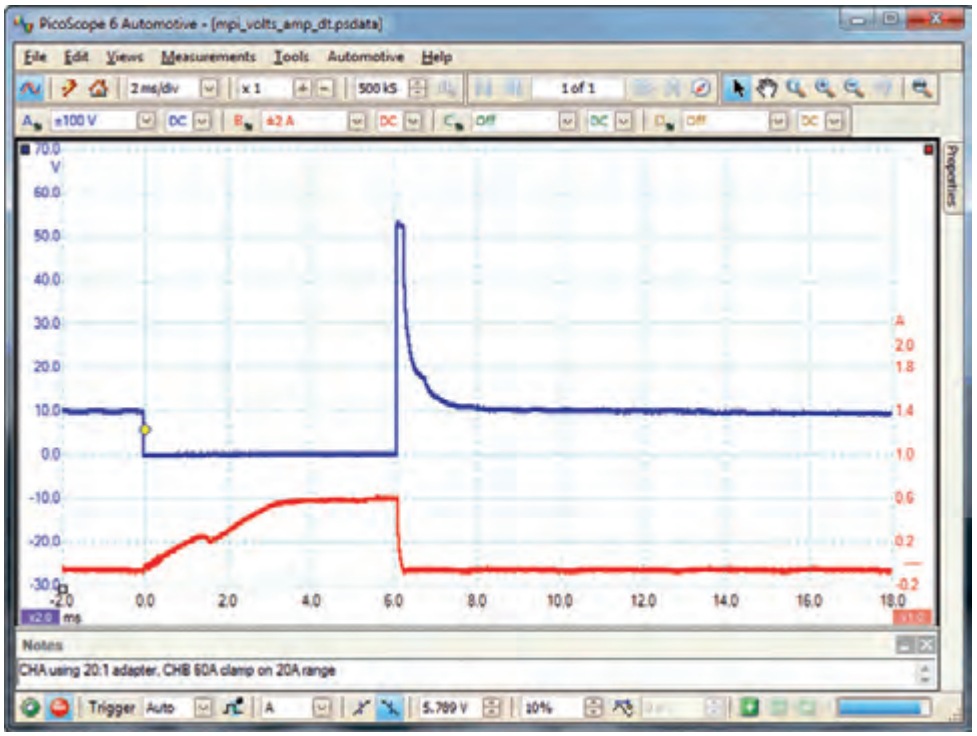


Figure 4.50 Multi-point injector waveform, red shows the current and blue the voltage signal

The f rst part of the current waveform is responsible for the electromagnetic force lifting the pintle; in this example, the time taken is approximately 1.5 ms. This is often referred to as the solenoid reaction time. The remaining 2 ms is the actual time the injector is fully open. This, when taken as a comparison against the injector voltage duration, is different to the 3.5 ms shown. The secret is to make sure you compare like with like!

4.3.4.3 Common rail diesel injector

Common rail diesel systems are becoming more erm, *common*, particularly in Europe (Figure 4.51).

It can be clearly seen from the example waveform that there are two distinctive points of injection, the f rst being the 'pre-injection' phase, with the second pulse being the 'main' injection phase (Figure 4.52).

As the throttle is opened, and the engine is accelerated, the 'main' injection pulse expands in a similar way to a petrol injector. As the throttle is released, the 'main' injection pulse disappears until such time as the engine returns to just above idle.

Under certain engine conditions, a third phase may be seen, this is called the 'post-injection' phase and is predominantly concerned with controlling the exhaust emissions.

4.3.4.4 Idle speed control valve

This device contains a winding, plunger and spring. When energised, the port opens, and when not, it closes (Figure 4.53).

The electromagnetic ISCV will have two electrical connections: usually a voltage supply at battery voltage and a switched earth.

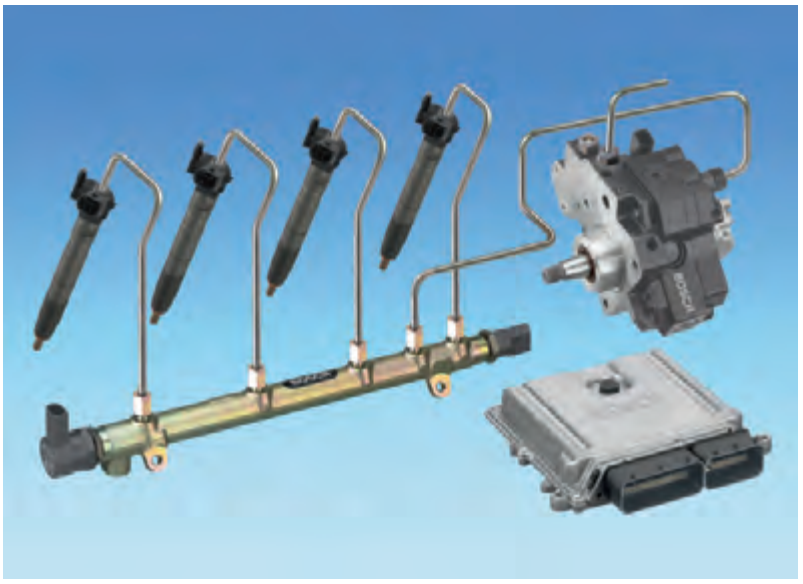


Figure 4.51 Common rail diesel pump, rail, injectors and ECU (Source: Bosch Press)

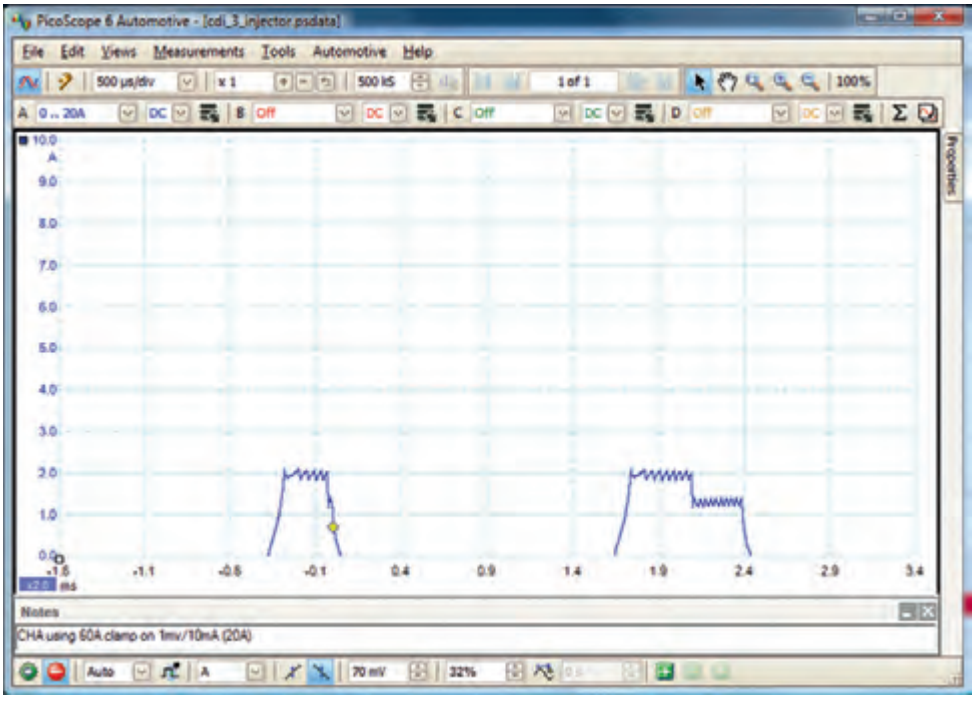


Figure 4.52 CR injector (current) waveform showing pre- and main injection pulses

Def nition

ISCV: Idle speed control valve.

The rate at which the device is switched is determined by the ECU to maintain a prerequisite speed according to its programming. The valve will form an air bypass around the throttle butterf y. If the engine has an adjustable air bypass and an ISCV, it may require a specif c routine to balance the two air paths. The position of the valve tends to take up an average position determined by the supplied signal. Probing onto the supply side will produce a straight line at system voltage (Figure 4.54).



Figure 4.53 Electromagnetic idle speed control valve

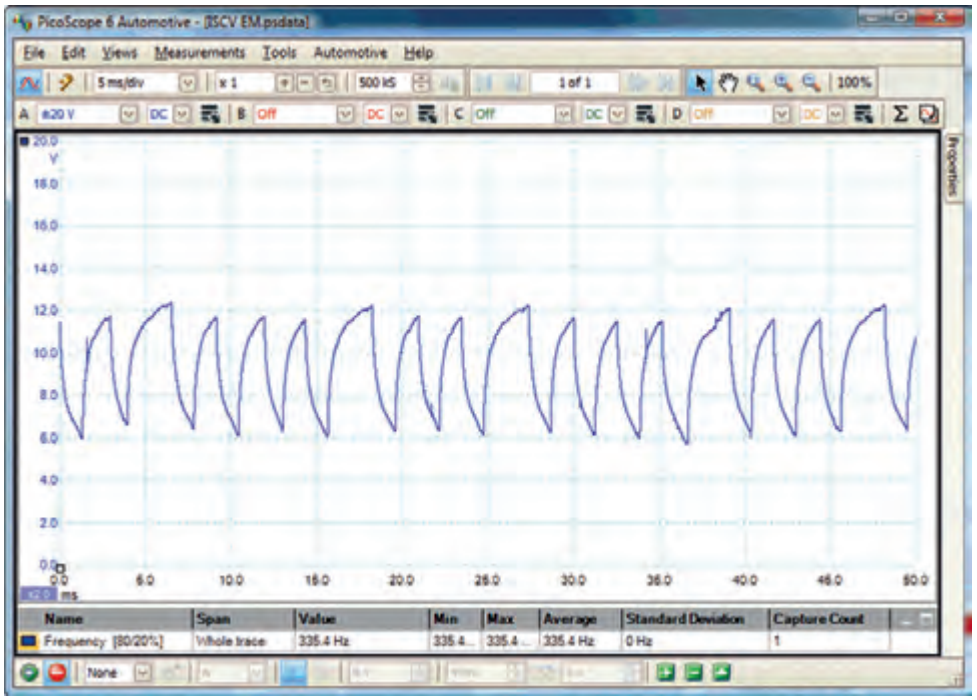


Figure 4.54 Signal produced by an electromagnetic idle speed control valve

4.3.4.5 Exhaust gas recirculation valve

Various types of exhaust gas recirculation (EGR) valve are in use based on simple solenoid operation. One development in actuator technology is the rotary electric exhaust gas recirculation (EEGR) valve for use in diesel engine applications. This device is shown in Figure 4.55. It has a self-cleaning action, accurate gas f ow control and a fast reaction speed.



Figure 4.55 Rotary EGR valve(Source: Delphi Media)

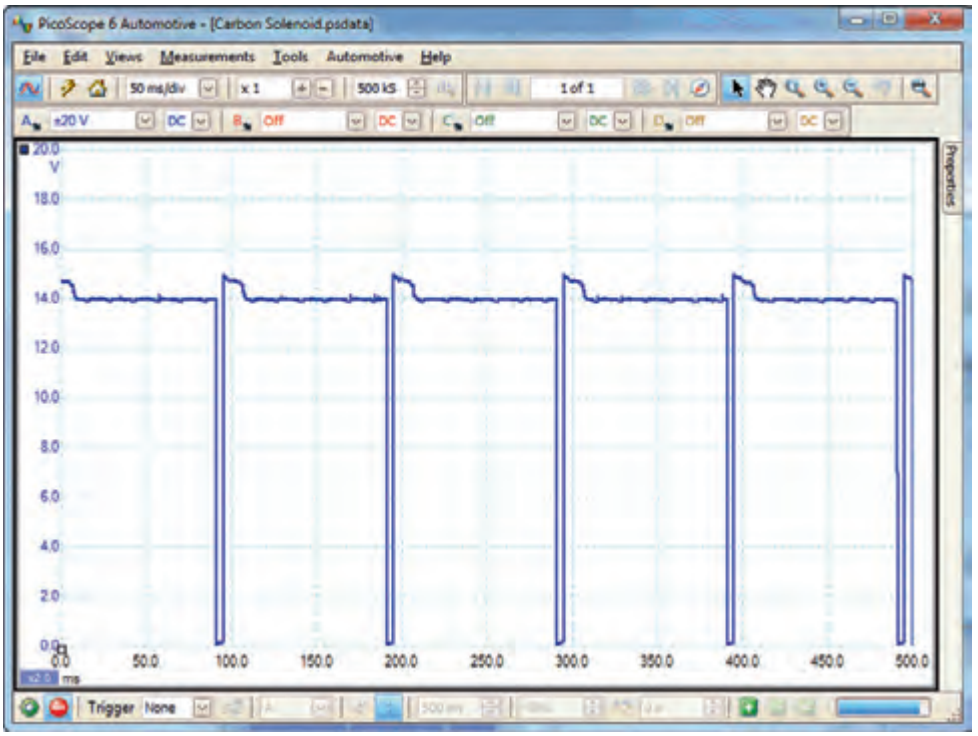


Figure 4.56 Carbon canister control valve signal

4.3.4.6 Carbon canister and other valves

There are a number of valves used that are effectively simple solenoid controlled devices. Measuring on one terminal will usually show battery supply voltage. The other terminal will show battery voltage when switched off and zero (ground or earth) voltage when the valve is switched on (Figure 4.56).

4.3.5 Thermal actuators

An example of a thermal actuator is the movement of a traditional type fuel or temperature gauge needle. A further example is an auxiliary air device used on many earlier fuel injection systems. The principle of the gauge is shown in Figure 4.57.

When current is supplied to the terminals, a heating element operates and causes a bimetallic strip to bend, which moves the pointer. The main advantage of this type of actuator, when used as an auxiliary device, apart from its simplicity, is that if it is placed in a suitable position, its reaction time will vary with the temperature of its surroundings. This is ideal for applications such as fast idle or cold starting control where, once the engine is hot, no action is required from the actuator.

Safety f rst

Even the earth path of the coil can produce over 350V – take care.

4.4 Engine waveforms

4.4.1 Ignition primary

The ignition primary waveform is a measurement of the voltage on the negative side of the ignition coil. The earth path of the coil can produce over

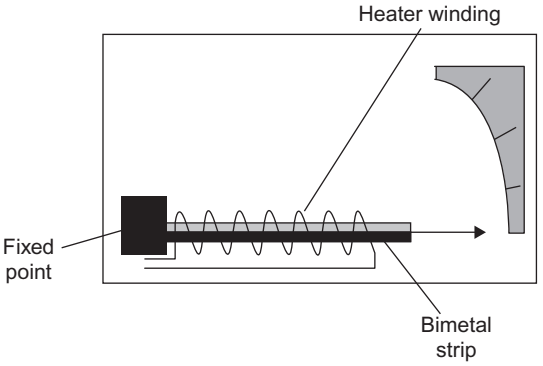


Figure 4.57 Thermal actuator used as a gauge

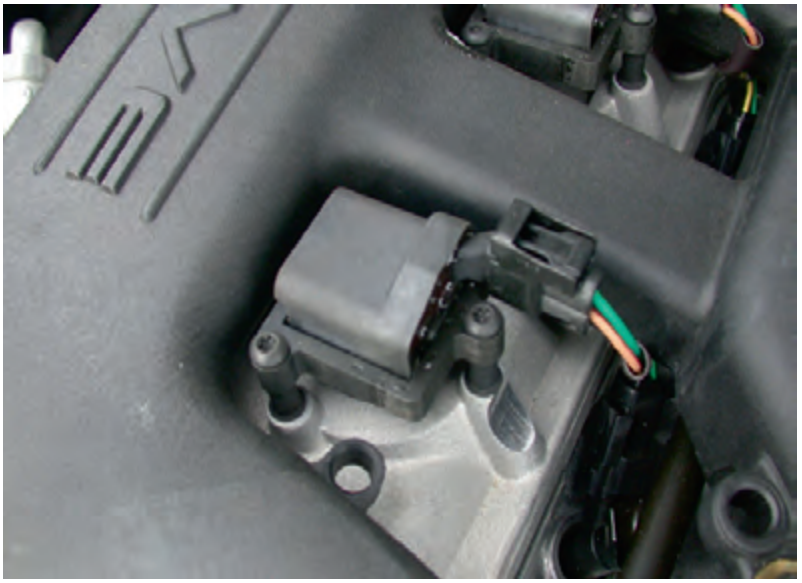


Figure 4.58 Coil on plug (COP) ignition

350 V. Different types of ignition coils produce slightly different traces but the fundamental parts of the trace and principles are the same (Figure 4.58).

In the waveform shown, the horizontal voltage line at the centre of the oscilloscope is at fairly constant voltage of approximately 30–40 V, which then drops sharply to what is referred to as the coil oscillation (Figure 4.59). The length of the horizontal voltage line is the 'spark duration' or 'burn time', which in this particular case is approximately 1 ms. The coil oscillation period should display a minimum of three to four peaks (both upper and lower). A loss of peaks would indicate a coil problem.

There is no current in the coil's primary circuit until the dwell period. This starts when the coil is earthed and the voltage drops to zero. The dwell period is controlled by the ignition amplif er or ECU and the length of the dwell is determined by the time it takes to build up to approximately 6 A. When this predetermined current has been reached, the amplif er stops increasing the primary current and it is maintained until the earth is removed from the coil. This is the precise moment of ignition.

The vertical line at the centre of the trace is in excess of 300 V, this is called the 'induced voltage'. The induced voltage is produced by magnetic inductance.

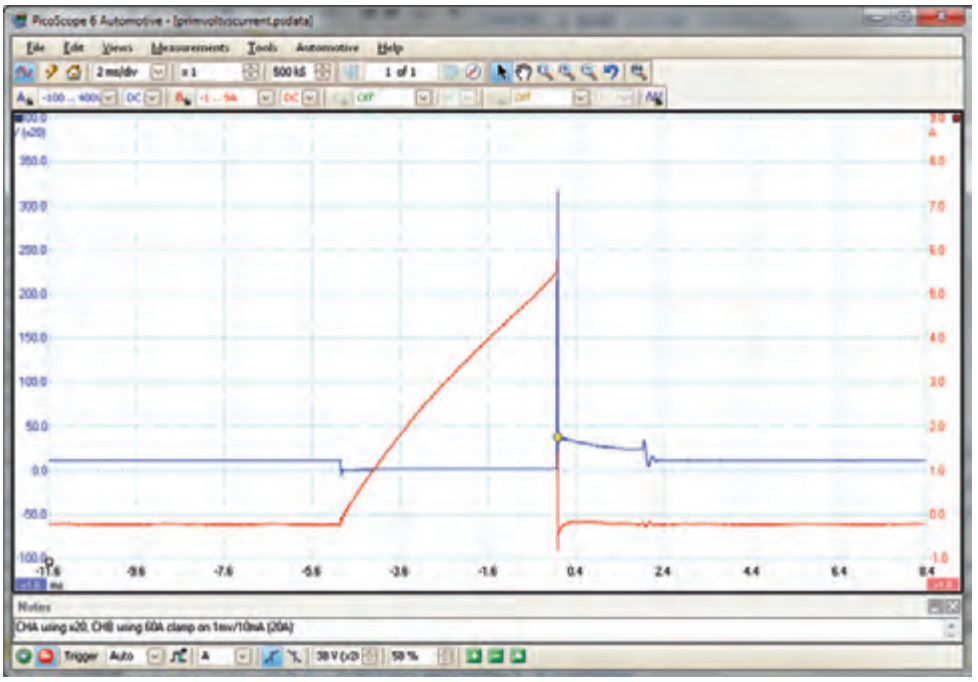


Figure 4.59 Primary ignition voltage and current traces

At the point of ignition, the coil's earth circuit is removed and the magnetic f ux collapses across the coil's windings. This induces a voltage between 150 and 350 V. The coil's high-tension (HT) output will be proportional to this induced voltage. The height of the induced voltage is sometimes referred to as the primary peak volts.

From the example current waveform, the limiting circuit can be seen in operation. The current switches on as the dwell period starts and rises until the required value is achieved (usually 6–8 A). At this point, the current is maintained until it is released at the point of ignition.

The dwell will expand as the engine revs are increased to maintain a constant coil saturation time. This gives rise to the term 'constant energy'. The coil saturation time can be measured and will remain the same regardless of the engine speed. The example shows a charge time of approximately 3.5 ms.

Safety f rst

Some coils can produce over 50 000 V – take care.

4.4.2 Ignition secondary

The ignition secondary waveform is a measurement of the HT output voltage from the ignition coil. Some coils can produce over 50 000 V. Different types of ignition coils produce slightly different traces but the fundamental parts of the trace and principles are the same (Figure 4.60).

The ignition secondary picture shown in the example waveform is from an engine f tted with electronic ignition. In this case, the waveform has been taken from the main coil lead (king lead). Suitable connection methods mean that similar traces can be seen for other types of ignition system (Figure 4.61).

The secondary waveform shows the length of time that the HT is f owing across the spark plug electrode after its initial voltage, which is required to initially jump the plug gap. This time is referred to as either the 'burn time' or the 'spark duration'. In the trace shown, it can be seen that the horizontal voltage line in the



Figure 4.60 Spark plugs(Source: Bosch Press)

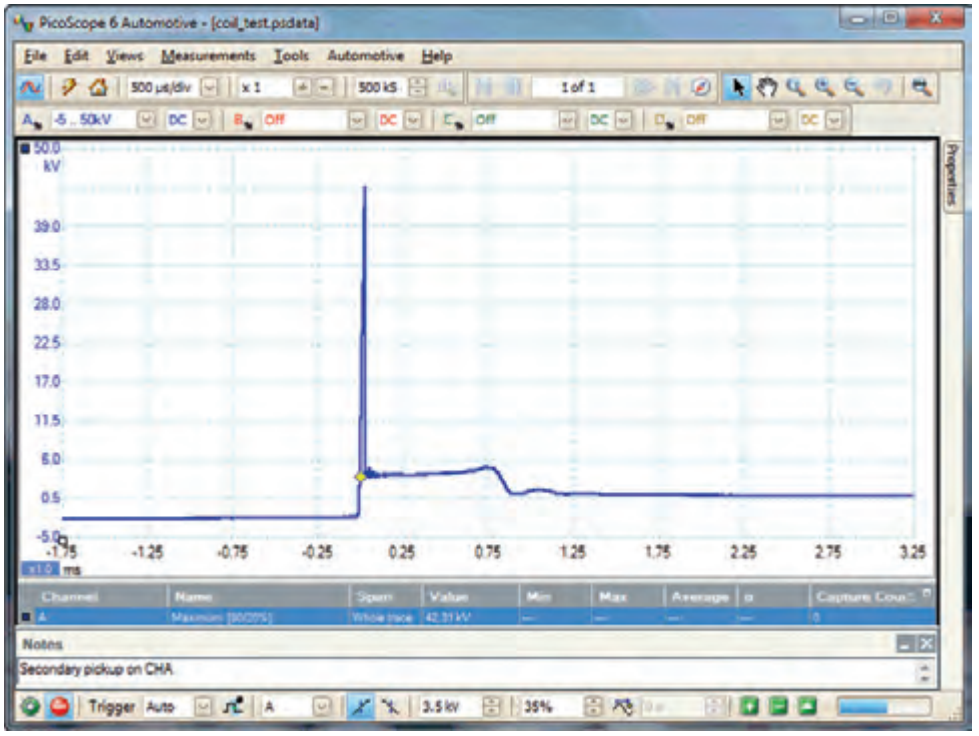


Figure 4.61 Ignition secondary trace

centre of the oscilloscope is at fairly constant voltage of approximately 4 or 5 kV, which then drops sharply into the 'coil oscillation' period.

The coil oscillation period should display a minimum of three or four peaks (same as for the primary trace). A loss of peaks indicates that the coil may be faulty. The period between the coil oscillation and the next 'drop down' is when the coil is at rest and there is no voltage in the secondary circuit. The 'drop down' is referred to as the 'polarity peak', and produces a small oscillation in the opposite

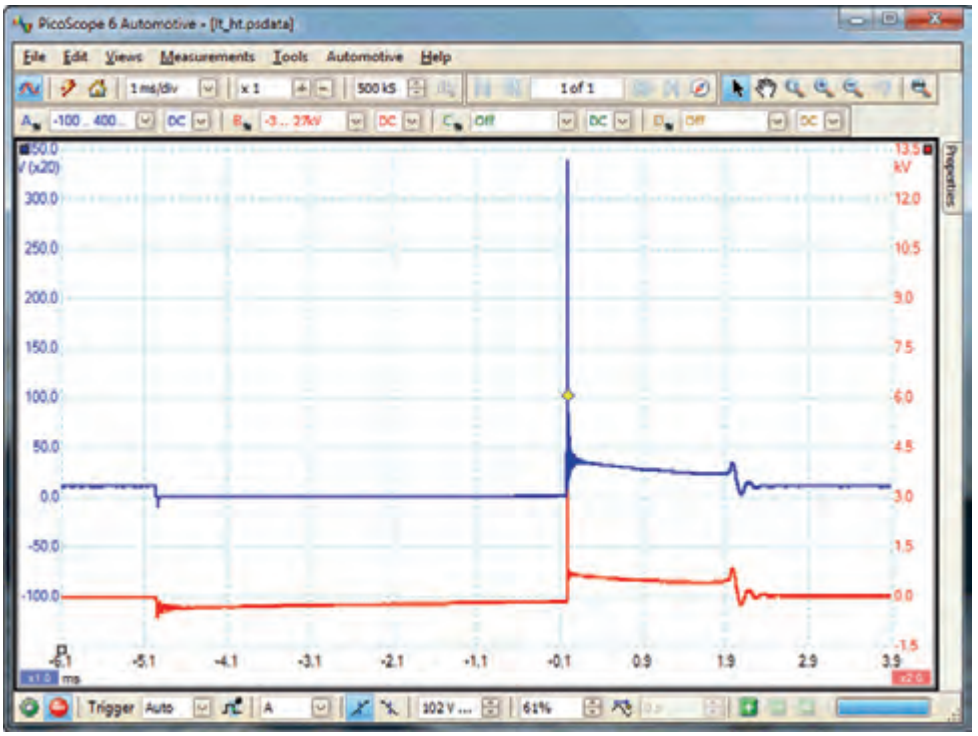


Figure 4.62 Distributorless ignition showing low and high tension (primary and secondary)

direction to the plug f ring voltage. This is due to the initial switching on of the coil's primary current.

The plug f ring voltage is the voltage required to jump and bridge the gap at the plug's electrode, commonly known as the 'plug kV'. In the example in Figure 4.61, the plug f ring voltage is approximately 45 kV.

When the plug kVs are recorded on a distributorless ignition system (DIS) or coil per cylinder ignition system, the voltage seen on the waveform should be in the 'upright position'. If the trace is inverted, it would suggest that either the wrong polarity has been selected from the menu or in the case of DIS, the inappropriate lead has been chosen. The plug voltage, while the engine is running, is continuously f uctuating and the display will be seen to move up and down. The maximum voltage at the spark plug can be seen as the 'Ch A: Maximum (kV)' reading at the bottom of the screen.

It is a useful test to snap the throttle and observe the voltage requirements when the engine is under load. This is the only time that the plugs are placed under any strain and is a fair assessment of how they will perform on the road.

Key fact

Fluctuations in voltage on the spark line could indicate poor combustion.

The second part of the waveform after the vertical line is known as the spark line voltage. This second voltage is the voltage required to keep the plug running after its initial spark to jump the gap. This voltage will be proportional to the resistance within the secondary circuit. The length of the line can be seen to run for approximately 2 ms.

4.4.3 Diesel glow plugs

A diesel glow plug is a simple heater. Measuring its current will indicate correct operation because as temperature increases in a glow plug so does resistance and therefore the current falls after an initial peak (Figure 4.63).

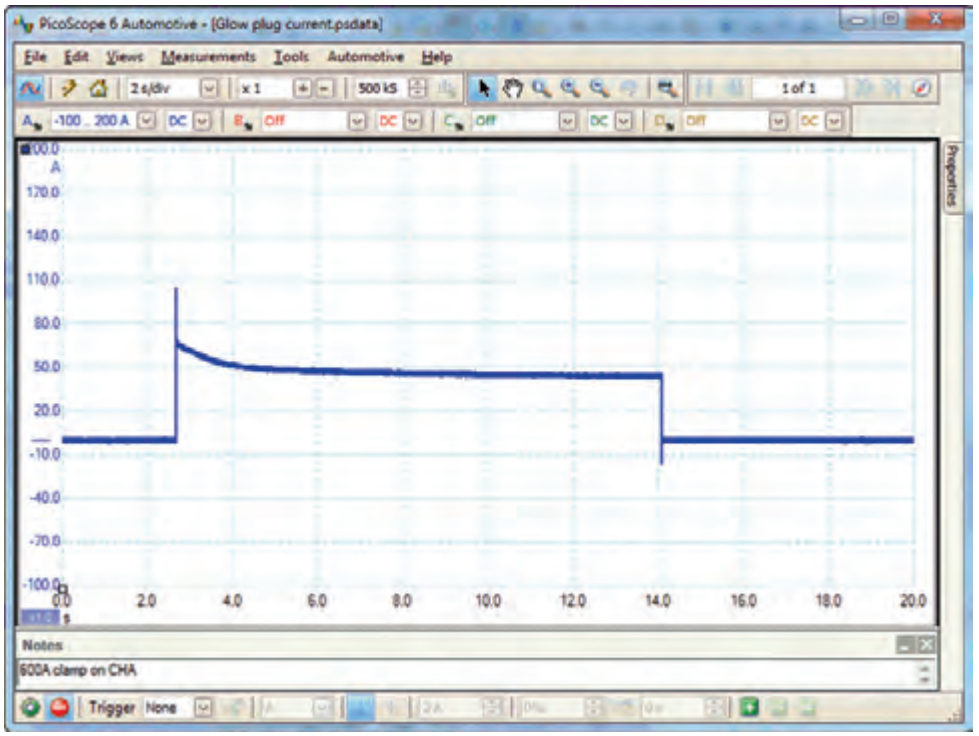


Figure 4.63 Glow plug current



Figure 4.64 Alternator (Source: Bosch Media)

4.4.4 Alternator waveform

Checking the ripple voltage produced by an alternator (Figure 4.64) is a very good way of assessing its condition.

The example waveform illustrates the rectif ed output from the alternator (Figure 4.65). The output shown is correct and there is no fault within the phase windings or the diodes (rectif er pack).

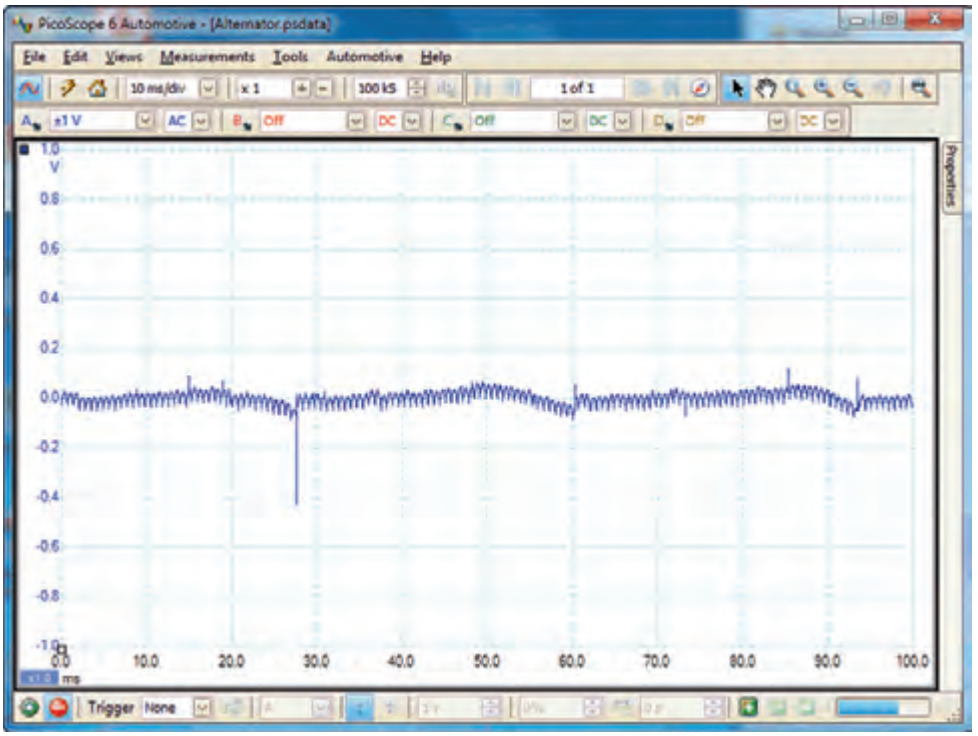


Figure 4.65 Alternator ripple voltage

The three phases from the alternator have been rectif ed to DC from its original AC and the waveform shows that the three phases are all functioning.

If the alternator is suffering from a diode fault, long downward 'tails' appear from the trace at regular intervals and 33% of the total current output will be lost. A fault within one of the three phases will show a similar picture to the one illustrated but is three or four times the height, with the base-to-peak voltage in excess of 1 V.

The voltage scale at the side of the oscilloscope is not representative of the charging voltage, but is used to show the upper and lower limits of the ripple. The 'amplitude' (voltage/height) of the waveform will vary under different conditions. A fully charged battery will show a 'f atter' picture, while a discharged battery will show an exaggerated amplitude until the battery is charged. Variations in the average voltage of the waveform are due to the action of the voltage regulator.

4.4.5 Relative compression petrol

Measuring the current drawn by the starter motor is useful to determine starter condition but it is also useful as an indicator of engine condition (Figure 4.66).

The purpose of this particular waveform is therefore to measure the current required to crank the engine and to evaluate the relative compressions.

The amperage required to crank the engine depends on many factors, such as the capacity of the engine, number of cylinders, viscosity of the oil, condition of the starter motor, condition of the starter's wiring circuit and compressions in the cylinders. Therefore, to evaluate the compressions, it is essential that the battery is charged and the starter and associated circuit are in good condition.

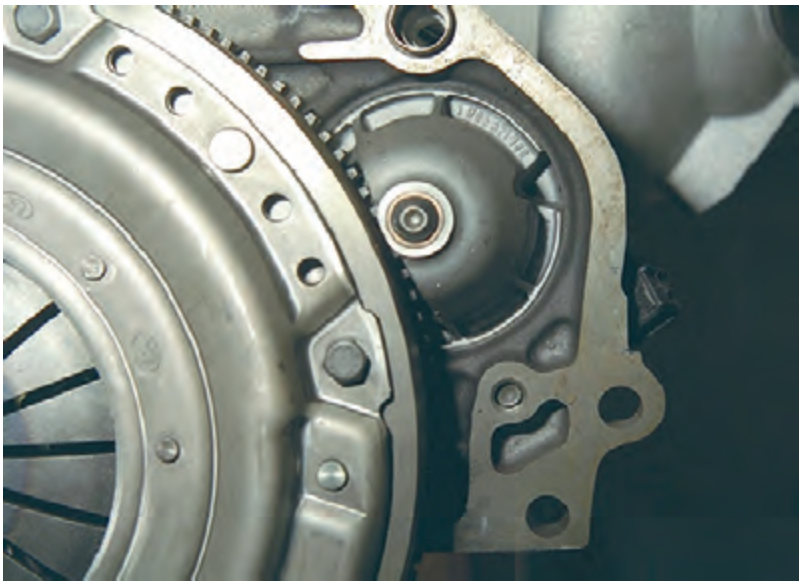


Figure 4.66 Starter and ring gear

The current for a typical four cylinder petrol/gasoline engine is in the region of 100–200 A. In the waveform shown (Figure 4.67), the initial peak of current (approximately 300 A) is the current required to overcome the initial friction and inertia to rotate the engine. Once the engine is rotating, the current will drop. It is also worth mentioning the small step before the initial peak, which is being caused by the switching of the starter solenoid.

The compressions can be compared against each other by monitoring the current required to push each cylinder up on its compression stroke. The better the compression, the higher the current demand and vice versa. It is therefore important that the current draw on each cylinder is equal.

4.5 Communication networks

There are three common multiplexed communication systems in current use. These systems reduce the number of wires needed and also allow information from sensors or different ECUs to be shared across a network. The three main systems are

- CAN;
- LIN;
- FlexRay.

4.5.1 CAN

Controller area network (CAN) is a protocol used to send information around a vehicle on data bus. It is made up of voltage pulses that represent ones and zeros, in other words, binary signals. The data is applied to two wires known as CAN high and CAN low (Figure 4.68).

In this display, it is possible to verify that data is being continuously exchanged along the CAN bus. It is also possible to check that the peak-to-peak voltage

Def nition

DLC: Diagnostic/Data link connector

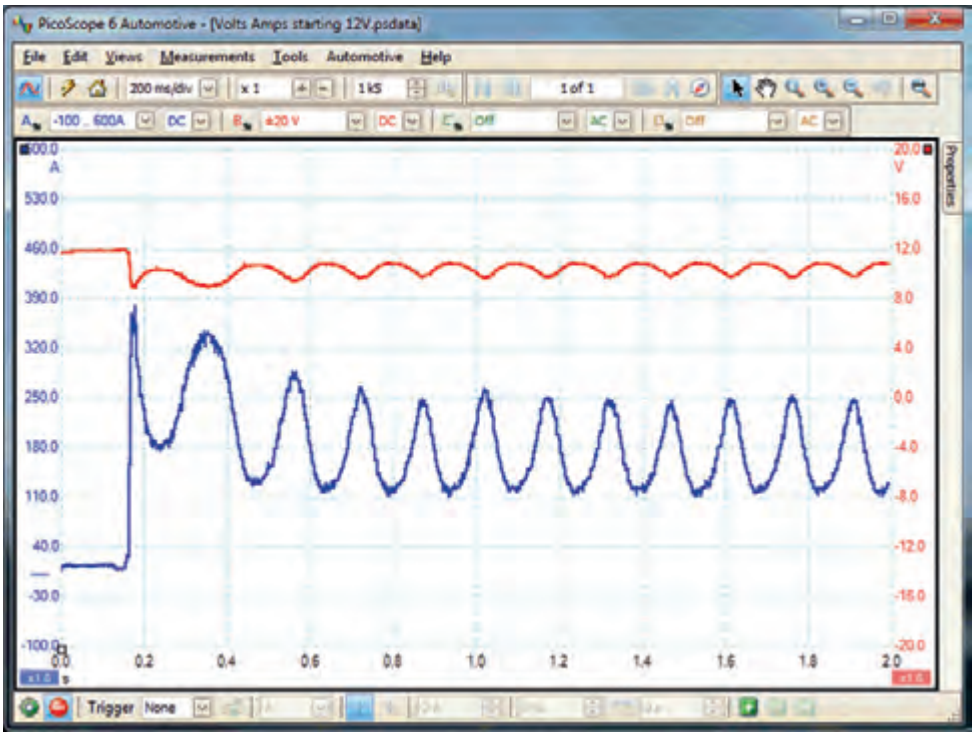


Figure 4.67 Spark ignition engine cranking amps



Figure 4.68 DLC socket – pin 6 is CAN high and pin 14 is CAN low

levels are correct and that a signal is present on both CAN lines. CAN uses a differential signal, and the signal on one line should be a coincident mirror image (the signals should line up) of the data on the other line (Figure 4.69).

The usual reason for examining the CAN signals is where a CAN fault has been indicated by on-board diagnostics, or to check the CAN connection to a suspected faulty CAN node. The vehicle manufacturers' manual should be referred to for precise waveform parameters.

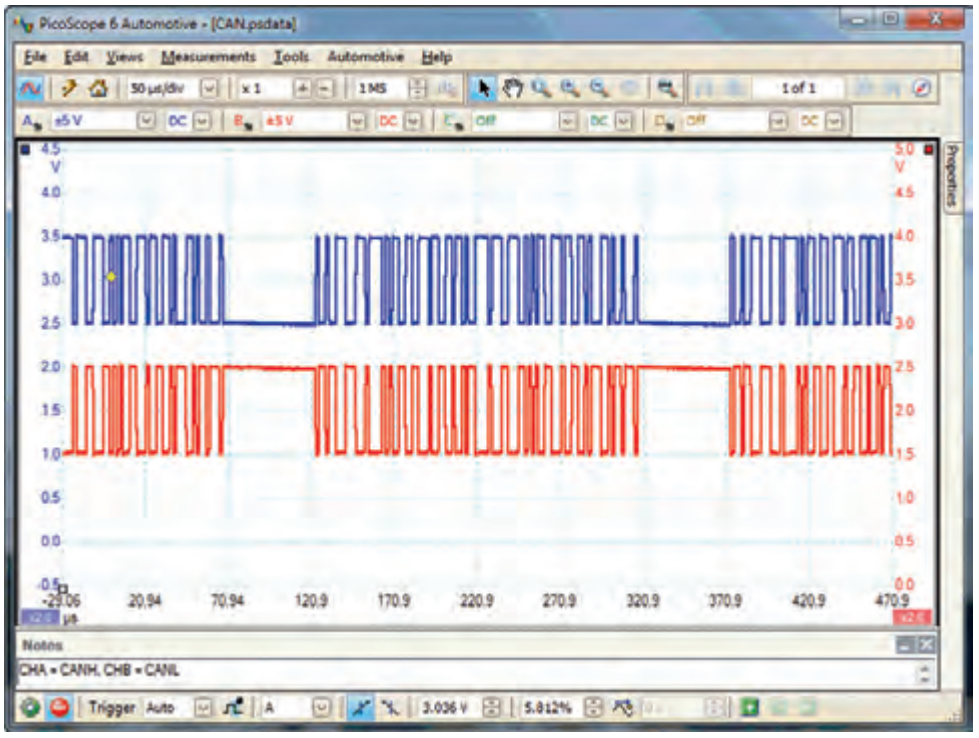


Figure 4.69 CAN high and low signals on a dual trace scope

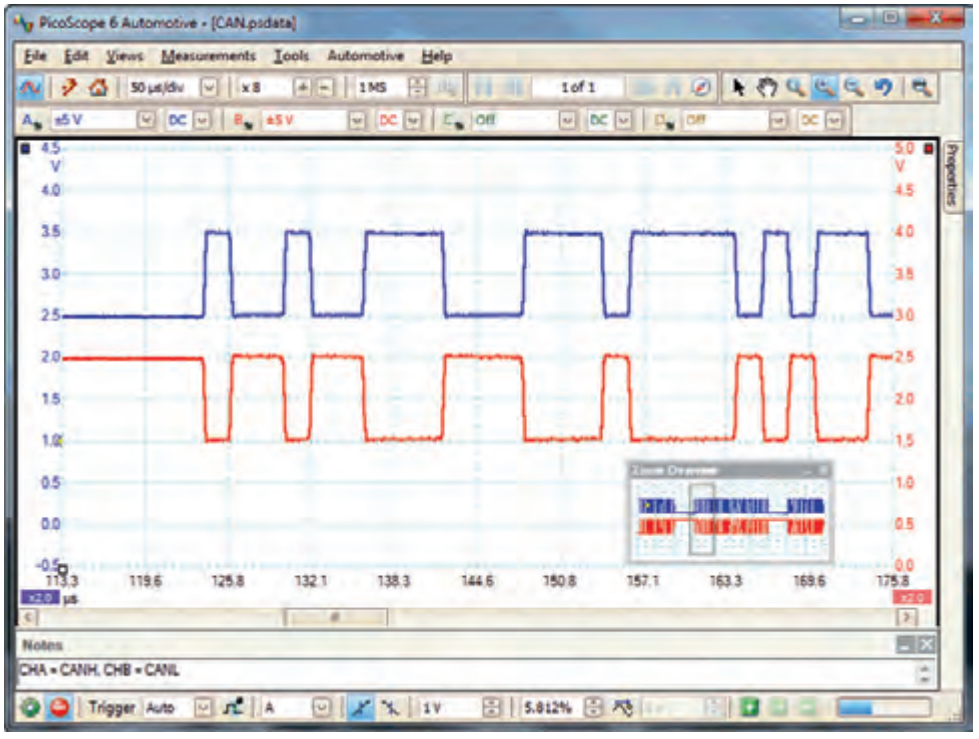


Figure 4.70 CAN signal zoomed in

When the signal is captured on a fast timebase (or zoomed in), it allows the individual state changes to be viewed. This enables the mirror image nature of the signals and the coincidence of the edges to be verif ed (Figure 4.70).

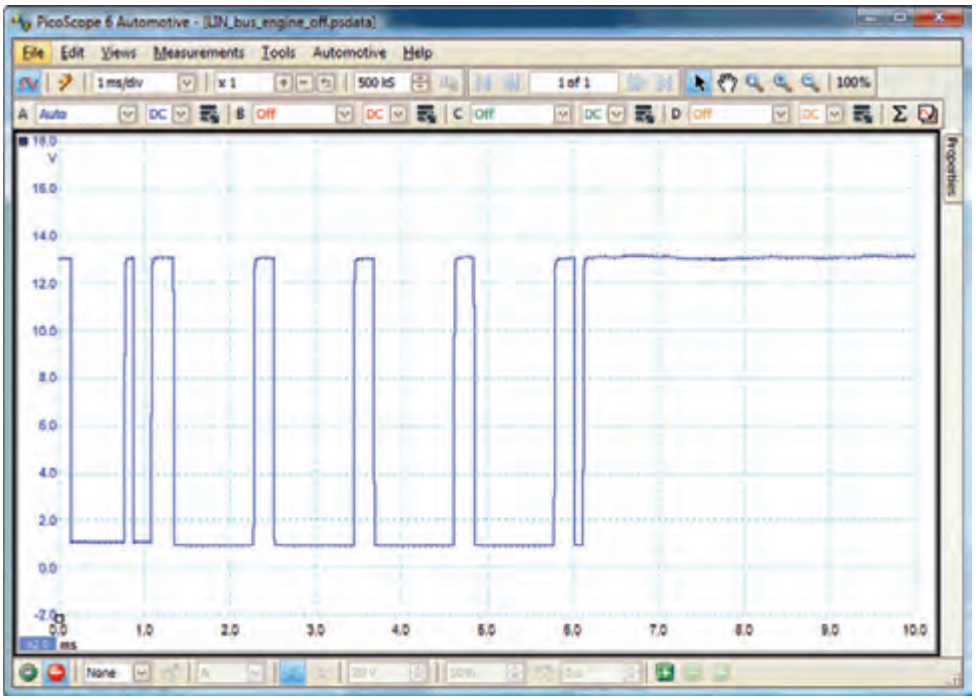


Figure 4.71 LIN waveform

4.5.2 LIN

Definition

LIN: Local interconnect network.

Local interconnect network (LIN) bus communication is becoming more common on modern CAN bus–equipped vehicles. It is a low-speed, single-wire serial data bus and a sub-bus of the faster, more complex CAN bus. It is used to control low-speed non-safety-critical housekeeping functions on the vehicle, especially windows, mirrors, locks, HVAC units and electric seats.

The LIN bus is proving popular because of its low cost and also because it reduces the bus load of the supervising CAN network.

LIN signals can be measured by connecting between earth/ground and the signal wire. It is not possible to decode the signal but a correctly switching square waveform should be shown (Figure 4.71).

4.5.3 FlexRay

FlexRay uses very high speed signals, so it is necessary to use high-speed probes (these are supplied with an advanced diagnostics kit) (Figure 4.72). The FlexRay-high and FlexRay-low pins are usually available at the multi-way connector at each ECU on the network.

It is possible to verify that data is being continuously exchanged on the FlexRay network, that the peak-to-peak voltage levels are correct and that a signal is present on both FlexRay lines. FlexRay uses a differential signal, so the signal on one line should be a mirror image of the data on the other line (Figure 4.73).

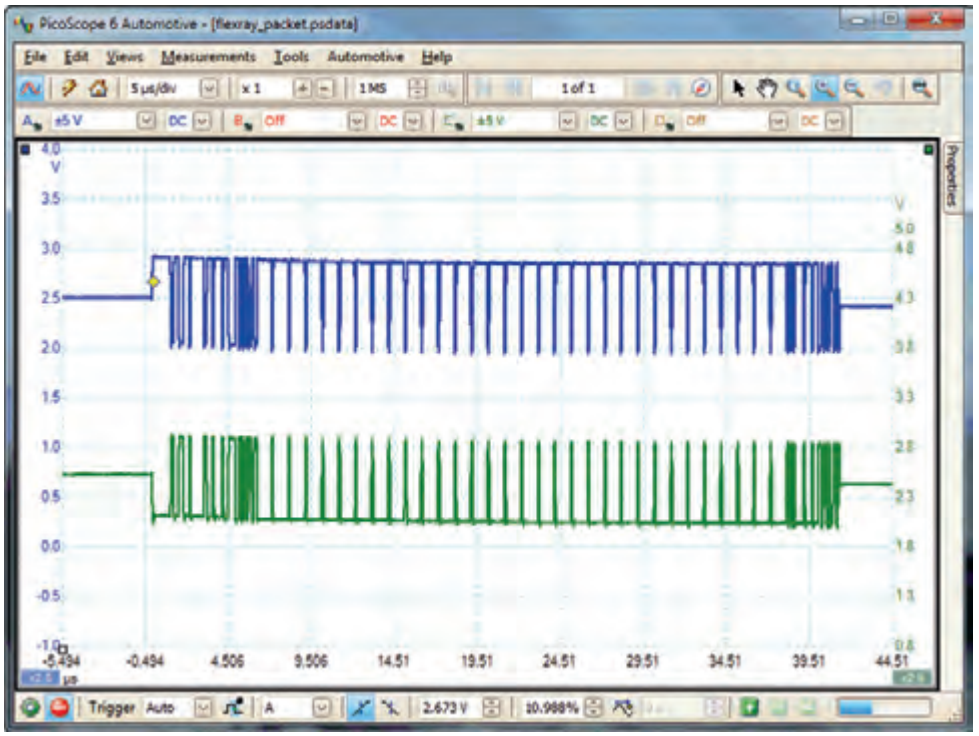


Figure 4.72 FlexRay signal

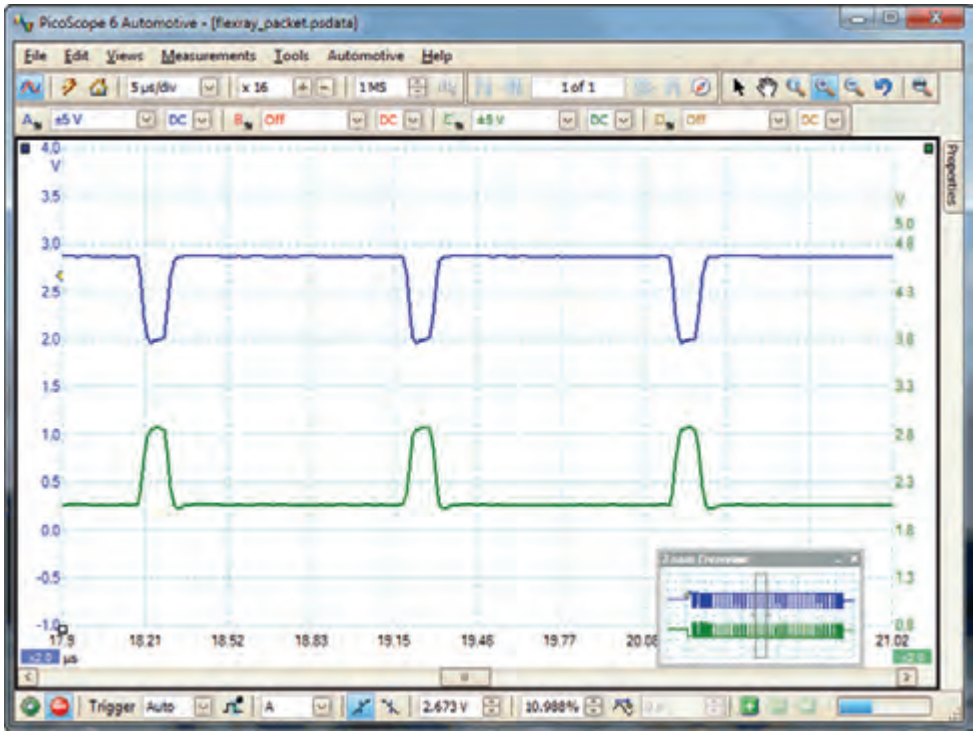


Figure 4.73 A closer view of a FlexRay signal

4.6 Summary

'Scope' diagnostics, particularly for sensors and actuators, is now an essential skill for the technician to develop. As with all diagnostic techniques that use test equipment, it is necessary for the user to know how

1 the vehicle system operates;
2 to connect the equipment;
3 readings should be interpreted.

Remember that an oscilloscope is actually just a voltmeter or ammeter, but it draws a picture of the readings over a set period of time. Learn what good waveforms look like, and then you will be able to make good judgements about what is wrong when they are not so good.

Acknowledgement

I am grateful to PicoTech for permission to use waveforms from their extensive library. Visit http://www.picotech.com for more information.

CHAPTER

On-board diagnostics

5.1 History

5.1.1 Introduction

Originating in the United States, and subsequently followed by Europe, Asia and many others, now governments around the globe have augmented vehicle emissions control legislation. This includes a requirement that all vehicles sold within their territories must support an on-board diagnostic (OBD) system that can be operated to determine the serviceability of the vehicle's emission control systems, sub-systems and components.

Enabled by the increasing advances in electronics and microprocessor software development, this system, now commonly termed as OBD, has been developed over recent years and is now implemented by all major motor vehicle manufacturers. Furthermore, this has been extended to allow diagnosis of non-emission-related vehicle systems.

5.1.2 Vehicle emissions and environmental health

From as early as 1930, the subject of vehicle engine emissions inf uencing environmental health was very topical in the state of California. Already with a population of 2 million vehicles, scores of people died and thousands became sick due to air pollution–related illnesses (Figure 5.1).

In 1943, following the outbreak of the Second World War, the population of California had risen to some 7 million people with 2.8 million vehicles travelling over a total of 24 billion miles. Already, smog was apparent and people suffered with stinging eyes, sore throat and breathing diff culties. The local government initiated a study into the cause of the problem. Scientists at CALTEC and The University of California investigated the problem of smog.

In 1945, after the conclusion of the war, Los Angeles began its air pollution control program and established the Bureau of Smoke Control. On 10 June 1947, the then California governor Earl Warren signed the Air Pollution Control Act. By 1950, California's population had reached 11 million people. Total registered vehicles in California exceeded 4.5 million and vehicle miles travelled (VMT) was 44.5 billion. The search for the root cause of smog production went on. Reports of deaths in other countries became apparent, for example, thousands of people died in London of a 'mystery fog' (Figure 5.2).

In 1952, Dr Arie Haagen-Smit determined the root cause of smog production. He surmised that engine pollutants, carbon monoxide (CO), hydrocarbons



Figure 5.1 Early traffc jam

Def nition

VMT: Vehicle miles travelled.

Advanced Automotive Fault Diagnosis.
© 2012 Tom Denton. Published by Routledge. All rights reserved.



Figure 5.2 Smog over Los Angeles

(HC) and various oxides of nitrogen (NO_x) combine to generate the smog, which consists of ozone and carbon dioxide.

Carbon dioxide is a pollutant, which is now said to contribute to global warming and climate change. Ozone, occupying a region of the lower atmosphere, is now known to cause respiratory ill health and lung disease and is also thought to make a much greater contribution to the greenhouse effect than even carbon dioxide.

The state became a centre for environmental activism. Naturally, amidst a public outcry to preserve the local environment, the state began to legislate for controls on motor vehicle emissions. So began an initiative that would span over 50 years, one that would drive change in a world industry and lead the world in the f ght for clean air.

5.1.3 History of the emissions control legislation

In 1960, the Motor Vehicle Pollution Control Board was established with a mandate to certify devices proposed to be f tted on cars for sale in California. In addition, the Federal Motor Vehicle Act of 1960 was enacted, requiring federal research to combat motor vehicle engine pollution. Manufacturers made technology improvements, and during this period, California's population reached 16 million. Total registered vehicles approached 8 million and VMT was 71 billion.

In 1961, in an effort to control HC crankcase emissions, the f rst piece of vehicle emissions control legislation mandating the use of specif c hardware was issued. Positive crankcase ventilation (PCV) controls HC crankcase emissions by extracting gases from the crankcase and recirculating them back into the fresh air/fuel charge in the cylinders.

A key turning point in history, in 1966, the California Motor Vehicle Pollution Control Board pioneered the adoption of vehicle tailpipe emissions standards for HC and CO and the California Highway Patrol began random roadside inspections of the smog control devices f tted to vehicles.

The following year, the governor of California, Ronald Reagan, signed the Mulford-Carrell Air Resources Act. This effectively allowed the state of

Table 5.1 California state-wide average emissions per vehicle, 1969

NO_x (g/mile)	HC (g/mile)
5.3	8.6

Table 5.2 California state-wide average emissions per vehicle, 1980

NO_x (g/mile)	HC (g/mile)
4.8	5.5

Definition

CARB: California Air Resources Board.

California to set its own emissions standards. The same year saw the formation of the California Air Resources Board (CARB), which was created from the amalgamation of the Motor Vehicle Pollution Control Board and the Bureau of Air Sanitation.

In 1969, the first California State Ambient Air Quality Standards are extended by California for photochemical oxidants, suspended particulates, sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and CO. California's population reached 20 million people. Total registered vehicles exceeded 12 million and VMT was 110 billion.

Total cumulative California vehicle emissions for HC and NO_x are estimated at 1.6 million tons/year (Table 5.1). In 1970, the US Environmental Protection Agency (EPA) was created. Its primary directive was, and still is, to protect all aspects of the environment. The next seven years witnessed further development of emissions control legislation and increasing employment of vehicle emissions control technology.

In 1971, CARB adopted the first vehicle NO_x standards. The EPA announced National Ambient Air Quality Standards for particulates, HC, CO, NO_2, photochemical oxidants (including ozone) and SO_2.

The first two-way catalytic converters came into use in 1975 as part of CARB's Motor Vehicle Emission Control Program followed by an announcement that CARB will limit lead in gasoline.

In 1977, Volvo introduced a vehicle marketed as 'Smog-Free'. This vehicle supported the first three-way catalytic (TWC) converter to control HC, NO_x and CO emissions.

In 1980, the California population reached 24 million people. Total registered vehicles were in the region of 17 million and VMT was 155 billion (Table 5.2).

Total cumulative California vehicle emissions for NO_x and HCs remain at 1970 levels of 1.6 million tons/year, despite a rise of 45 billion in VMT over those 10 years.

The legislative controls had clearly begun to have a positive effect. Spurred on by this victory, CARB began a program of compliance testing on 'in-use' vehicles in order to determine whether they continue to comply with emission standards as vehicle mileage increases. Vehicle manufacturers commissioned the development of more durable emission control systems.

Introduction of the biennial California Smog Check Program was seen in 1984, the aim of which was to identify vehicles in need of maintenance and to confirm the effectiveness of their emissions control systems (Figure 5.3).



1943: First smog alarm in LA
1950: 4,5 Mio. vehicles in California
1952: Dr Arie Haagen-Smit analyses the reasons for smog development
1960: 8 Mio. vehicles in California
1961: Introduction of crankcase ventilation (PCV)
1966: Federal Clean Air Act
1967: Foundation of CARB, Chairman: Haagen-Smit
1970: Foundation of EPA
1980: 17 Mio. vehicles in California
1988: CARB decides OBD II for 1994 MY
1990: Number of smog days goes down, CARB decides LEV and ZEV - program
1995: 26 Mio. vehicles in California
1996: Ozon pollution 59% below 1965, number of smog days 94% below 1975

Figure 5.3 History of CARB emission legislation activity

The mid-term period of emissions control legislation ended in 1988 with a key announcement, which saw the beginning of on-board diagnostics. The California Clean Air Act was signed and CARB adopted regulations that required that all 1994 and beyond model year cars were f tted with 'on-board diagnostic' systems. The task of these systems was, as it is now:

> *To monitor the vehicle emissions control systems performance and alert owners when there is a malfunction that results in the lack of function of an emissions control system/sub-system or component.*

5.1.4 Introduction of vehicle emissions control strategies

To meet the ever increasing but justif able and 'wanted' need of vehicle emissions control legislation, vehicle manufacturers were forced to invest heavily in the research and development of Vehicle Emission Control Strategies. Building upon the foundation laid by PCV, the two-way and three-way catalyst, manufacturers further developed emissions control hardware. Such systems included exhaust gas recirculation, secondary air injection, fuel tank canister purge, spark timing adjustment, air/fuel ratio (AFR) control biasing, fuel shut off under negative torque conditions (overrun or cruise down), to name but a few.

This development continued and expanded meaning that these systems demanded an ever-increasing array of sensors and actuators. The resolution of measurement, control of AFR, actuator displacement rates and accuracy of displacement, etc. was way beyond that which could be provided by traditional existing mechanical technologies.

At about this time, an enabler was provided in the form of recent advances in microprocessor technology. The path was clear, the drivers for OBD system monitoring were in force and the enablers were available. On-board diagnostics was born.

5.2 What is on-board diagnostics?

Fundamentally, a contemporary microprocessor-based on-board diagnostics or OBD system is intended to self-diagnose and report when the performance of the vehicle's emissions control systems or components have degraded. This is to the extent that the tailpipe emissions have exceeded legislated levels or are likely to be exceeded in the long term.

When an issue occurs, the OBD system illuminates a warning lamp known as the malfunction indicator lamp (MIL) or malfunction indicator (MI) on the instrument cluster. In the United States, this symbol often appears with the phrase 'Check Engine', 'Check' or 'Service Engine Soon' contained within it. European vehicles tend to use the engine symbol on an orange background (Figure 5.4).



Figure 5.4 Malfunction indicator lamp symbols

When the fault occurs, the system stores a diagnostic trouble code (DTC) that can be used to trace and identify the fault. The system will also store important information that pertains to the operating conditions of the vehicle when the fault was set. A service technician is able to connect a diagnostic scan tool or a code reader that will communicate with the microprocessor and retrieve this information. This allows the technician to diagnose and rectify the fault, make a repair/replacement, reset the OBD system and restore the vehicle emissions control system to a serviceable status.

Key fact

When the fault occurs, the system stores a diagnostic trouble code (DTC).

As vehicles and their systems become more complex, the functionality of OBD is being extended to cover vehicle systems and components that do not have anything to do with vehicle emissions control. Vehicle body, chassis and accessories such as air conditioning or door modules can now also be interrogated to determine their serviceability as an aid to fault diagnosis.

5.2.1 OBD scenario example

While driving, a vehicle owner observes that the vehicle's engine 'lacks power' and 'jumps sometimes'. This is a problem often faced by technicians in that customers often have no engineering or automotive knowledge and use lay terms to describe what is happening with a very complex system. The driver does, however, report that the MIL has been illuminated.

The technician connects a scan tool that can communicate using an industry standard communications protocol. The OBD code memory is checked and data is presented in a way that also conforms to a standard. DTC P1101 with the description 'MAF sensor out of self-test range' is stored in memory, which means that the OBD system component monitor has identif ed the mass airf ow (MAF) sensor circuit voltage as outside an acceptable range (Figure 5.5).

Def nition

FMEM: Failure mode effects management allows the driver to take the vehicle to a place of repair Also described as 'limp home' mode.

Upon conf rming the fault the system was smart, it defaulted to a 'safe' value of MAF, a concept known as failure mode effects management (FMEM), to allow the driver to take the vehicle to a place of repair. While this FMEM value was a good short-term solution, it is not a suff cient substitute for the full functionality of a serviceable MAF sensor.

Since the MAF sensor determines the MAF going into the engine intake, it will be impossible for the system to run at the optimum AFR for eff cient burning of the air/fuel charge within the cylinder. It may be that tailpipe emissions are likely to rise beyond legislated limits.

Also, the MAF sensor is used by other emissions control systems on the vehicle, now that its input is unreliable it follows that those systems are no longer working



Figure 5.5 Hot wire MAF sensor (Source: Bosch)

at their optimum levels and may not work at all. This is the reason for the MIL illumination, which says, in as many words, 'An emissions control system/sub system or component has become unserviceable!'

Visual inspection of the MAF sensor reveals that it has become damaged beyond repair and needs replacing. This is carried out, the technician clears the DTC from the OBD system memory, resets the system, and takes a short test drive; later the diagnostic scan tool confirms that the DTC is no longer present. The road test also confirms that the previous drive issue is no longer apparent.

5.2.2 Origins of OBD in the United States

The previous example relates to the current situation, but when OBD was first introduced, standards and practices were less well defined. Manufacturers developed and applied their own systems and code descriptions. This state of affairs was obviously undesirable since non-franchised service and repair centres had to understand the various subtleties of each system; this meant having different scan tools, as well as a multitude of leads, manuals and connectors. This made diagnostics unwieldy and expensive. This stage became known as 'OBD1', the first stage of OBD introduction.

In the late 1980s, the Society of Automotive Engineers (SAE) defined a list of standard practices and recommended these to the EPA. The EPA acknowledged the benefits of these standards and recommendations, and adopted them. In combination, they changed the shape and application of OBD. The recommendations included having a standard diagnostic connector, a standard scan tool and a communications protocol that the standard scan tool could use to interface with the vehicle of any manufacturer.

The standard also included mandatory structures and descriptions for certain emission control system/component defects. These were called 'P0' codes. Manufacturers were still free to generate their own 'manufacturer-specific code descriptions' known as 'P1' codes. This phase of implementation became known as OBD2 and was adopted for implementation by 1 January 1996.

Key fact

OBD2 was adopted for implementation by 1 January 1996.

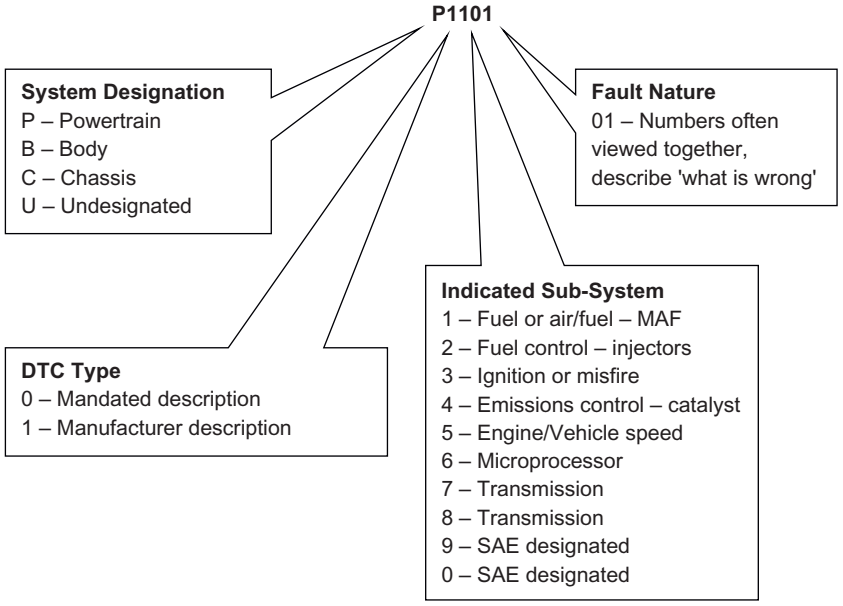


Figure 5.6 P-code composition

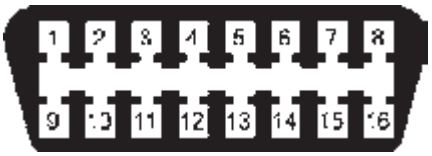


Figure 5.7 Sixteen pin DLC OBD2/EOBD connector

5.2.3 P-code composition

The DTC is displayed as a f ve-character alphanumeric code. The f rst character is a letter that def nes which vehicle system set the code, be it powertrain, body or chassis.

- P means powertrain system set the code.
- B means body system set the code.
- C means chassis system set the code.
- U is currently unused but has been ‘stolen’ to represent communication errors.

P codes are requested by the microprocessor controlling the powertrain or transmission and refer to the emissions control systems and their components.

B codes are requested by the microprocessor controlling the body control systems. Collectively these are grouped as lighting, air conditioning, instrumentation or even in-car entertainment or telematics.

C codes are requested by the microprocessor controlling the chassis systems that control vehicle dynamics such as ride height adjustment, traction control, etc.

The four numbers that follow the letter detail information pertaining to what sub-system declared the code. Using the example from before, see Figure 5.6.

An integral feature of the OBD system is its ability to store fault codes relating to problems that occur with the engine electronic control system, particularly faults that could affect the emission control system, and this is one of its primary functions. For the diagnostic technician, this is a powerful feature which can clearly assist in locating and rectifying problems on the vehicle when they occur.

The diagnostic socket used by systems conforming to European OBD (EOBD)/OBD2 standards should have the following pin conf guration (Figure 5.7):

1 ignition positive supply;
2 bus + line, SAE J1850 (PWM);

3 manufacturer's discretion;
4 chassis ground;
5 signal ground;
6 CAN bus H;
7 K-line;
8 manufacturer's discretion;
9 manufacturer's discretion;
10 bus – line (PWM);
11 manufacturer's discretion;
12 manufacturer's discretion;
13 manufacturer's discretion;
14 CAN bus L;
15 L-line or second K-line;
16 vehicle battery positive.

With the introduction of OBD2 and EOBD, this feature was made even more powerful by making it more accessible. Standardisation of the interface connector known as the diagnostic link connector (DLC) and communication protocol allowed the development of generic scan tools, which could be used on any OBD compliant vehicle.

5.2.4 European on-board diagnostics and global adoption

Europe was not immune to the environmental issues associated with smog. A major smog episode occurred in London in December 1952; this lasted for f ve days and resulted in approximately 4000 deaths. The UK government passed its f rst Clean Air Act in 1956, which aimed to control domestic sources of smoke pollution.

In 1970, the then European community adopted directive 70/220 EEC – 'Measures to be taken against Air Pollution by Emissions from Motor Vehicles'. This basically set the foundation for future legislation to curb motor vehicle pollution in Europe. This directive was amended over the next three decades when in October 1998 the amendment 98/69/EC 'On-Board Diagnostics (OBD) for Motor Vehicles' was adopted, which added Annex XI to the original 70/220 document. Annex XI details the functional aspects of OBD for motor vehicles in Europe and across the globe. This became known as EOBD.

5.2.5 Summary

A major contributing factor to environmental health issues in the United States was found to be motor vehicle emissions pollution. Scientif c studies by government sponsored academic establishments and vehicle manufacturers then took place over several years. Legislative bodies were formed, which later developed and enacted vehicle emissions control legislation that forced vehicle manufacturers to develop control strategies and incorporate them within their production vehicles.

As microprocessor technologies became more advanced and commercially viable, the legislation was augmented to include a self-diagnosing OBD system, which would report when the emissions control system was unserviceable. First

attempts by manufacturers to use such a system were applied unilaterally, which resulted in confusion, regenerative work and a poor reception of the OBD (now termed OBD1) concept. A revision of the legislation adopted SAE recommended standards, which resulted in the OBD (now termed OBD2) system becoming largely generic and applicable across the whole range of vehicle manufacturers.

As environmental activism spread across to Europe, vehicle manufacturers realised they had to support a philosophy of sustainable growth. Similar legislation was adopted and EOBD manifested itself in a form very similar to that observed in the United States.

5.3 Petrol/Gasoline on-board diagnostic monitors

5.3.1 Introduction

This section will cover the fundamentals of some of the OBD systems employed on mainstream petrol/gasoline vehicles. The concept of how the OBD system is divided into a series of software-based serviceability indicators, known as 'OBD monitors', is also covered.

5.3.2 Legislative drivers

In Europe, the European Directive 70/220 EEC was supplemented by European Directive 98/69/EC (Year: 1998: OJ Series: L – OJ Number: 350/1). This introduced legislation mandating the use of OBD systems in passenger vehicles manufactured and sold after 1 January 2001.

In the United States, legislation was f rst introduced in California by the California Air Resources Board (CARB) in 1988 and later federally by the Clean Air Act Amendments of 1990. This meant that the enforcing body, the EPA, requires that states have to develop state implementation plans (SIPs) that explain how each state will implement a plan to clean up pollution from sources including motor vehicles. One aspect of the requirement is the performance of OBD system checks as part of the required periodic inspection.

In order to be compliant with legislation and sell vehicles, manufacturers needed to engineer 'early warning' monitoring sub-systems that would determine when emission control systems had malfunctioned to the extent that tailpipe emissions had (or were likely to in the long term) exceeded a legislated level. OBD 'monitors' were derived for this purpose.

5.3.3 Component monitoring

The emission control systems integral with the vehicle employ many sensors and actuators. A software program housed within a microprocessor def nes their actions.

The 'component monitor' is responsible for determining the serviceability of these sensors and actuators. Intelligent component drivers linked to the microprocessor have the ability to enable/disable sensors/actuators and to receive signals. The analogue inputs from the sensors are converted to digital values within the microprocessor.

In combination with these component drivers, the microprocessor possesses the functionality to detect circuit faults on the links between microprocessor and

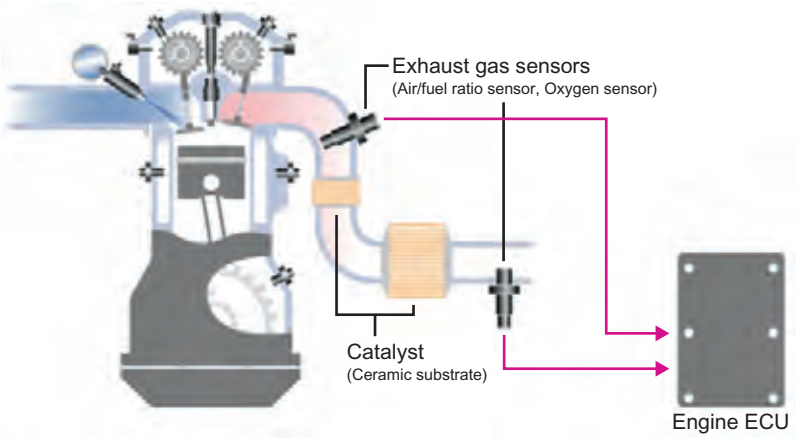


Figure 5.8 Exhaust gas oxygen sensors positioned pre- and post-catalyst (Source: http://www.globaldensoproducts.com)

component. In addition, rationality tests can be performed to determine whether the sensor is operating out of range of its specif cation.

5.3.4 Rationality testing

Rationality tests can be performed on such sensors as the MAF sensor and throttle body. For example, the MAF is tested by observing its output value in comparison to a 'mapped' value normalised by throttle position and engine speed. The map or table contains expected MAF output values for the engine speed/throttle set point.

Should the MAF output lie outside of an acceptable range (threshold) of values for that engine speed/throttle set point, then a fault is reported.

5.3.5 Circuit testing

The component monitor is capable of monitoring for circuit faults. Open circuits, short circuits to ground or voltage can be detected. Many manufacturers also include logic to detect intermittent errors.

5.3.6 Catalyst monitor

The purpose of the catalyst is to reduce tailpipe/exhaust emissions. The 'catalyst monitor' is responsible for determining the eff ciency of the catalyst by inferring its ability to store oxygen. The method favoured most by the majority of manufacturers is to f t an oxygen sensor before and after the catalyst.

As the catalyst's ability to store oxygen (and hence perform three-way catalysis) deteriorates, the oxygen sensor downstream of the sensor will respond to the oxygen in the exhaust gas stream and its signal response will exhibit a characteristic similar to the upstream oxygen sensor (Figures 5.8 and 5.9).

An algorithm within the microprocessor analyses this signal and determines whether the eff ciency of the catalyst has degraded beyond the point where the vehicle tailpipe emissions exceed legislated levels. If the microprocessor determines that this has occurred, then a malfunction and a DTC are reported. Repeat detections of a failed catalyst will result in MIL illumination (Figure 5.10).

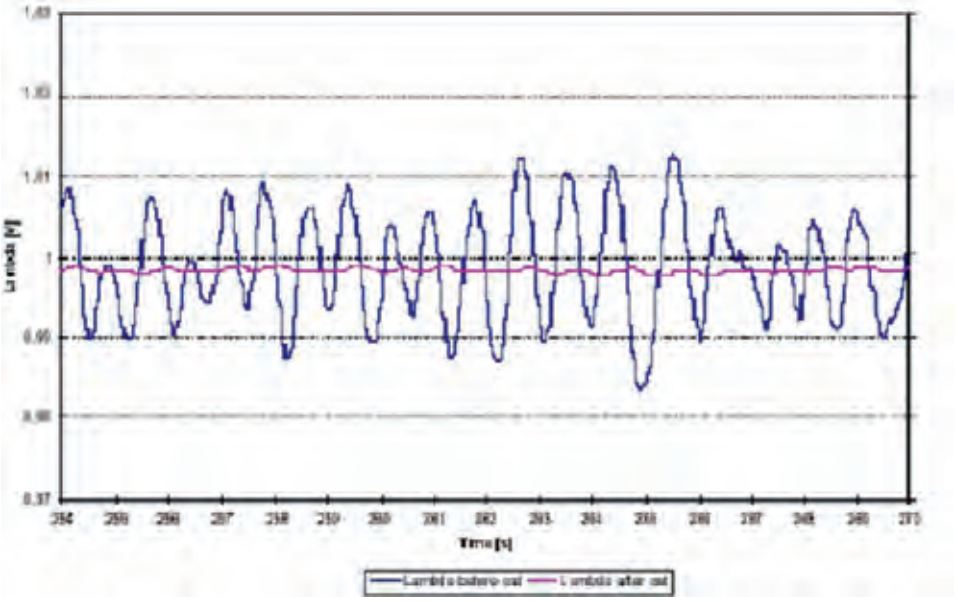


Figure 5.9 Upstream and downstream exhaust gas sensor activity – good catalyst (Source: SAE 2001-01-0933 New Cat Preparation Procedure for OBD2 Monitoring Requirements)

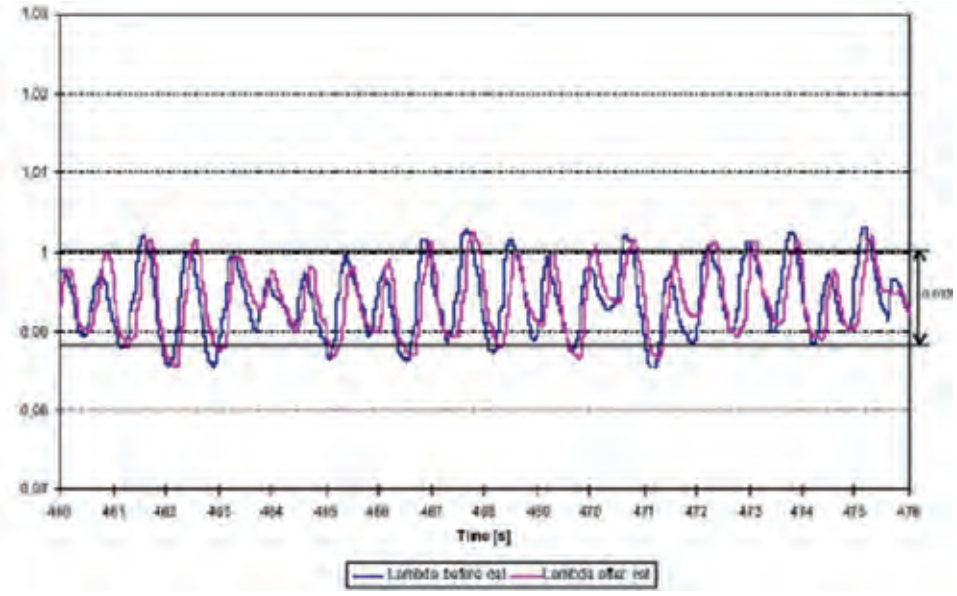


Figure 5.10 Upstream and downstream exhaust gas sensor activity – failed catalyst (Source: SAE 2001-01-0933 New Cat Preparation Procedure for OBD2 Monitoring Requirements)

5.3.7 Evaporative system monitor

The purpose of the evaporative (EVAP) emissions control system is to store and subsequently dispose off unburned HC emissions, thus preventing them from entering the atmosphere. This is achieved by applying a vacuum across the fuel tank. The vacuum then causes fuel vapour to be drawn through a carbon canister in which the HC vapours are collected and stored.

Evaporative emissions control system

1 Line from fuel tank to carbon canister. **2** Carbon canister. **3** Fresh air. **4** Canister-purge valve. **5** Line to intake manifold. **6** Throttle valve.
p_s Intake manifold pressure. p_u Atmospheric pressure. Δp Difference between intake manifold pressure and atmospheric pressure.

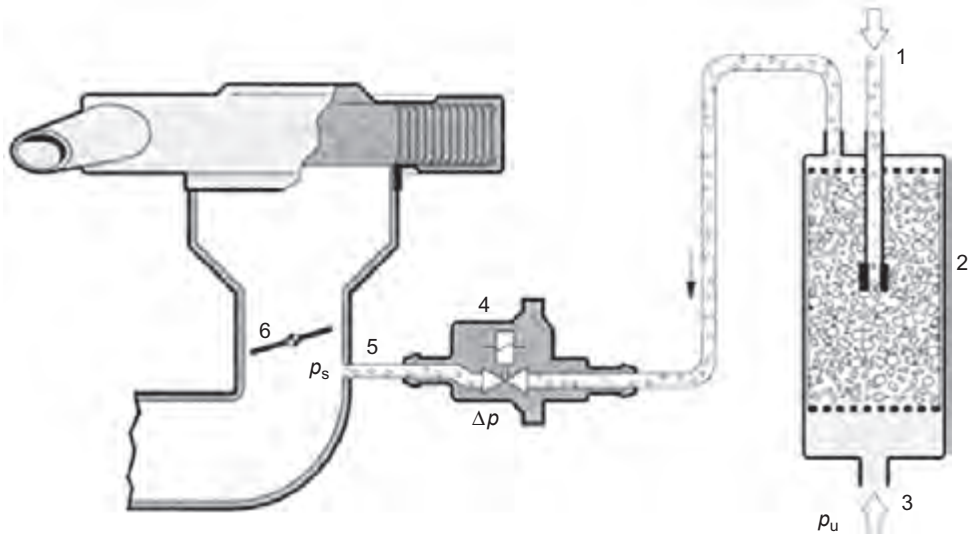


Figure 5.11 Evaporative emissions control system (Source: Bosch)

During certain closed loop fuel control conditions, the microprocessor activates a solenoid-controlled 'vapour management valve'. This allows the manifold vacuum to draw vapour from the carbon canister along vapour lines, which terminate in the intake manifold. The fuel vapour is then combined and combusted with the standard air/fuel charge; the closed loop fuel control system caters for the additional AFR enrichment to ensure that stoichiometric fuelling continues (Figure 5.11).

The evaporative system monitor is responsible for determining the serviceability of the EVAP system components and detecting leaks in the vapour lines. Most manufacturers check for fuel vapour leaks by employing a diagnostic that utilises a pressure or vacuum test on the fuel system.

European legislation dictates that these checks are not required. However, vehicles manufactured in the United States after 1996 and before 1999 generally employ a system that uses a pressure or vacuum system. This must be able to detect a leak in a hose or f ller cap that is equivalent to that generated by a hole, which is 0.040 inch (1 mm) in diameter. Vehicles manufactured after 2000 must support diagnostics that are capable of detecting a 0.020 inch (0.5 mm) hole.

5.3.8 Fuel system monitoring

As vehicles accumulate mileage so also do the components, sensors and actuators of the emissions control systems. MAF sensors become dirty and their response slows with age. Exhaust gas oxygen sensors also respond slower as they are subject to the in-f eld failure modes such as oil and fuel contamination, thermal stress and general ageing. Fuel pressure regulators perform outside of their optimum capacity; fuel injectors become slower in their response; and partial blockages mean that they deliver less and sometimes more fuel than requested.

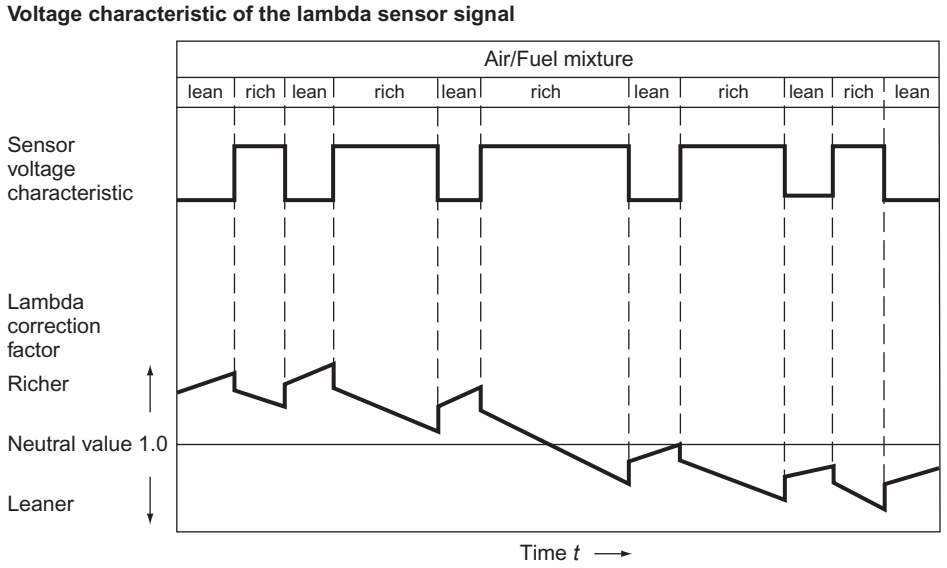


Figure 5.12 Rich AFR lambda sensor signal fuelling error (Source: Bosch)

If this component ageing were not compensated for, it would mean that the fuel system would not be able to maintain normal fuelling around stoichiometric AFR as shown in Figure 5.12. The end result would be the potential to exceed emission limits. A lambda value of one is required in order for the three-way catalyst to work. In addition to this, more severe fuelling errors would cause noticeable effects in the performance of the vehicle leading to customer complaints and potential to damage the manufacturer's brand image.

This compensation strategy is known as adaptive learning. A dedicated piece of software contained within the electronic control unit (ECU) learns these deviations away from stoichiometry, while the fuel system is in closed loop control. They are stored in a memory that is only reset when commanded by a technician and which is also robust to battery changes.

These memory-stored corrections are often termed 'long-term' fuel corrections. They are often stored in memory as a function of air mass, engine speed or engine load.

An exhaust gas oxygen sensor detects the amount of oxygen in the catalyst feed gas and the sensor produces a voltage, which is fed back to the microprocessor. This is then processed to determine the instantaneous or 'short-term' fuel correction to be applied. This is done in order to vary the fuel around stoichiometry and allow three-way catalysis to occur.

The microprocessor then calculates the amount of fuel required using an equation, which is shown here in its most basic form (Figure 5.13).

$$\text{Fuel mass} = \frac{\text{air mass} \times \text{long-term fuel trim}}{\text{short-term fuel trim} \times 14.64}$$

Referring to Figures 5.11 and 5.12, it can be seen that when there is a component malfunction, which causes the AFR in the exhaust stream to be rich, then there is a need to adapt to this to bring the AFR back into the region of stoichiometry. The value of the long-term fuel trim correction must decrease because less fuel is required.

Cyclic change between mixture adaptation and adaptation of the cylinder-charge factor

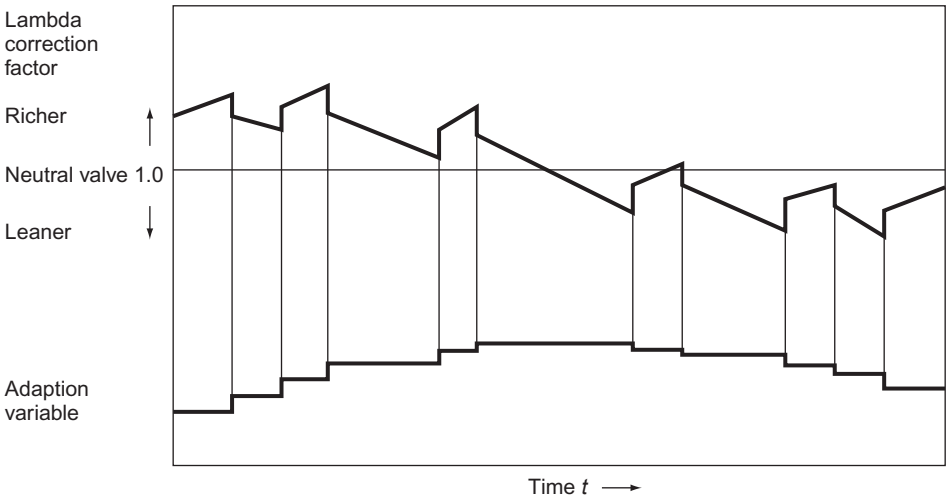


Figure 5.13 Adaptive fuel strategy in operation (Source: Bosch)

Should the situation continue and the problem causing rich AFR become slowly worse, the error adaption will continue with an ever-decreasing value for the long-term fuel trim being applied, learned and stored in memory.

The purpose of the fuel monitor is to determine when the amount of long-term adaptive correction has reached the point where the system can no longer cope. This is also where long-term fuel trim values reach a pre-def ned or 'calibrated' limit at which no further adaption to error is allowed. This limit is calibrated to coincide with exhaust tailpipe emissions exceeding legislated levels. At this point and when a short-term fuelling error exceeds another 'calibrated' limit, a DTC is stored, and after consecutive drives, the MI is illuminated.

The opposite occurs, with extra fuel being added, via the long-term fuel trim parameter, should an error occur that causes the AFR at the exhaust gas oxygen sensor to be lean.

5.3.9 Exhaust gas recirculation monitor

As combustion takes place within the engine cylinders, nitrogen and oxygen combine to form various oxides of nitrogen, collectively termed as NO_x. NO_x emissions can be reduced up to a certain point by enriching the AFR, beyond the point at which HC and CO emissions begin to increase. NO_x emissions are generated as a function of combustion temperature, so another way to reduce these is to decrease the compression ratio which leads to other ineff ciencies like poor fuel economy.

Most manufacturers employ an emissions control sub-system known as exhaust gas recirculation (EGR). This by def nition recirculates some of the exhaust gases back into the normal intake charge. These 'combusted' gases cannot be burnt again so they act to dilute the intake charge. As a result, in-cylinder temperatures are reduced along with NO_x emissions (Figure 5.14).

The EGR system monitor is responsible for determining the serviceability of the sensors, hoses, valves and actuators that belong to the EGR system. Manufacturers employ systems that can verify that the requested amount of exhaust gas is f owing back into the engine intake. Methods can be both

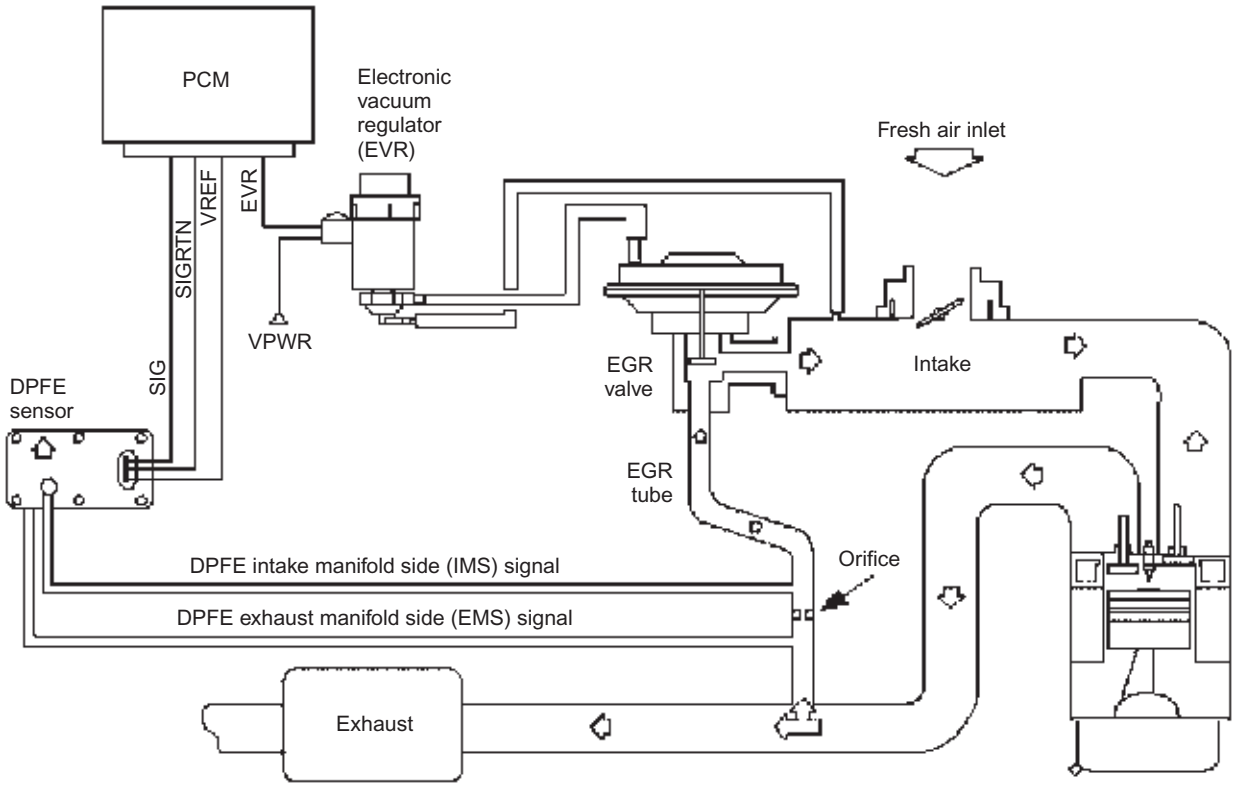


Figure 5.14 EGR system using differential pressure monitoring (Source: Ford Motor Company)

intrusive and non-intrusive, such as a change in manifold pressure as EGR f ows and is then shut off.

One method monitors AFR excursions after the EGR valve is opened, and then closed as the AFR becomes lean. Another system employs a differential pressure scheme that determines the pressure both upstream and downstream of the exhaust to determine whether the requested f ow rate is in effect. Yet another system employs a temperature sensor, which reports the change in temperature as EGR gases f ow past the sensor. The temperature change will be mapped against the amount of EGR f owing, so when an amount of EGR is requested, the f ow rate is inferred by measuring the change in temperature.

5.3.10 Secondary air monitor

The exhaust system catalyst is not immediately operative following a start where the engine and exhaust system is cool. Temperature thresholds above which the catalyst is working, and three-way catalysis is occurring, vary as a function of the exhaust gas system package. Typically, this 'light off' point occurs at temperatures of approximately 260 °C/500 °F. Some manufacturers employ electrically heated catalysts to reach this temperature rapidly, but these are expensive to manufacture and replace.

Most manufacturers rely on the exhaust gases as a source of heat in order to bring the catalyst up to light off temperature. When the vehicle is started from cold, the AFR is rich; this is required to ensure a stable engine start for cold pull-away. From an emissions perspective, the impact is observed in the production of HC and CO in the exhaust stream because the exhaust system catalyst has not reached light off.

Def nition

Catalyst light off temperature is the point at which it starts to operate fully.

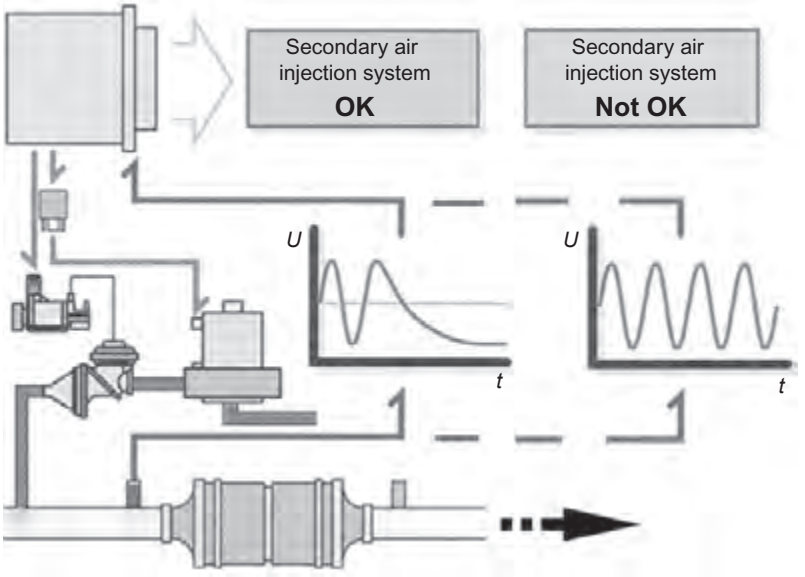


Figure 5.15 Secondary airfow diagnostic monitoring

The secondary air system uses a pump, which adds more air into the exhaust stream at a point before the catalyst follows a cold start. The secondary air combusts the HC in the catalyst, generating heat, which, in turn, promotes light off and further emissions reduction.

Older systems support a belt-driven mechanical pump with a bypass valve when secondary airf ow is not required. Modern vehicles employ an electric air pump operated by the engine-management ECU [powertrain control module (PCM)] via relays.

The secondary air monitor is responsible for determining the serviceability of the secondary air system components. Most strategies monitor the electrical components and ensure the system pumps air when requested by the ECU. To check the airf ow, the ECU observes the response of the exhaust gas oxygen sensor after it commands the fuel control system to enter open-loop control and force the AFR to become rich. The secondary air pump is then commanded on and the ECU determines the time taken for the exhaust gas oxygen sensor to indicate a lean AFR. If this time exceeds a calibrated threshold, a DTC is stored (Figure 5.15).

5.3.11 Monitors and readiness f ags

An important part of any OBD system is the system monitors and associated readiness f ags. These readiness f ags indicate when a monitor is active. Certain monitors are continuous, for example, misf re and fuel system monitors.

Monitor status (ready/not ready) indicates if a monitor has completed its self-evaluation sequence. System monitors are set to ‘not ready’ if cleared by scan tool and/or the battery is disconnected. Some of the monitors must test their components under specif c, appropriate preconditions:

- The evaporative system monitor has temperature and fuel f ll level constraints.
- The misf re monitor may ignore input on rough road surfaces to prevent false triggers.
- The oxygen sensor heater must monitor from a cold start.

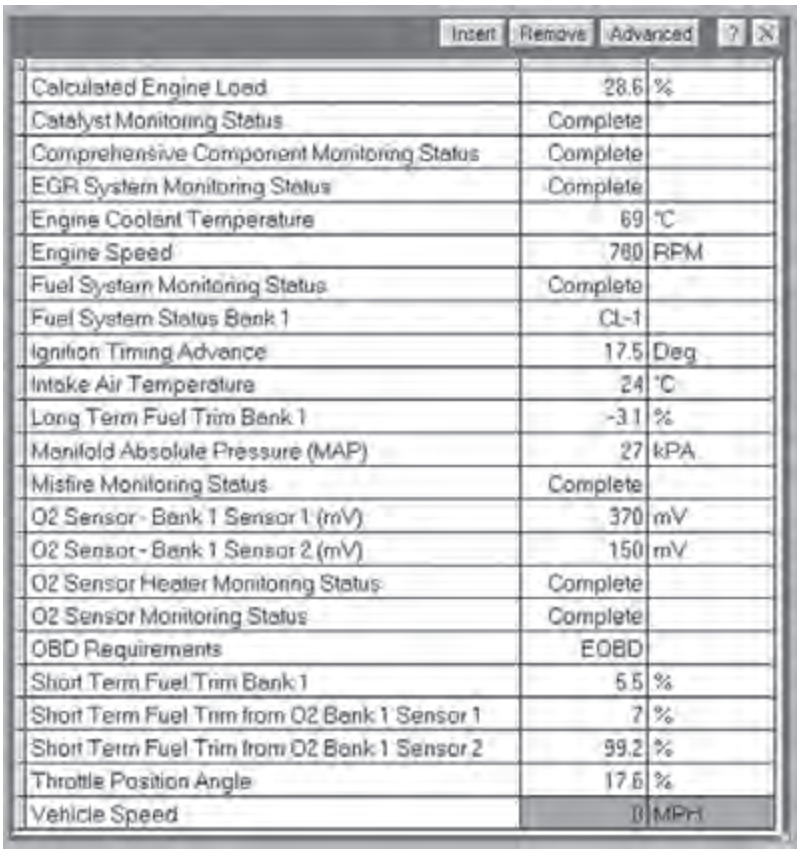


Figure 5.16 System monitors (marked as 'Complete') and live data shown in scan tool

Most other system monitors are not continuous and are only active under certain conditions. If these conditions are not fulf lled, then the readiness f ag for that monitor is set to 'not ready'. Until the readiness f ags are set appropriately, it is not possible to perform a test of the OBD system and its associated components (Figure 5.16).

There is no universal drive cycle that is guaranteed to set all the system monitors appropriately for a test of the OBD system. Most manufacturers and even cars have their own specif c requirements, and irrespective of this, there are still some specif c vehicles that have known issues when trying to set readiness f ag status. To allow for this vehicles of model year 1996–2000 are allowed two readiness f ags to be 'not ready'. After this, 2001 onwards, one readiness f ag is allowed to be 'not ready' prior to a test.

5.4 Misf re detection

5.4.1 Misf re monitor

When an engine endures a period of misf re, at best tailpipe emissions will increase and at worst catalyst damage and even destruction can occur. When misf re occurs, the unburned fuel and air is discharged direct to the exhaust system where it passes directly through the catalyst.

Subsequent normal combustion events can combust this air/fuel charge in something akin to a bellows effect, which causes catalyst temperatures to rise considerably. Catalyst damage failure thresholds are package specif c but are in

Key fact

When a misfe occurs, unburned fuel and air pass through the catalyst and can cause damage.

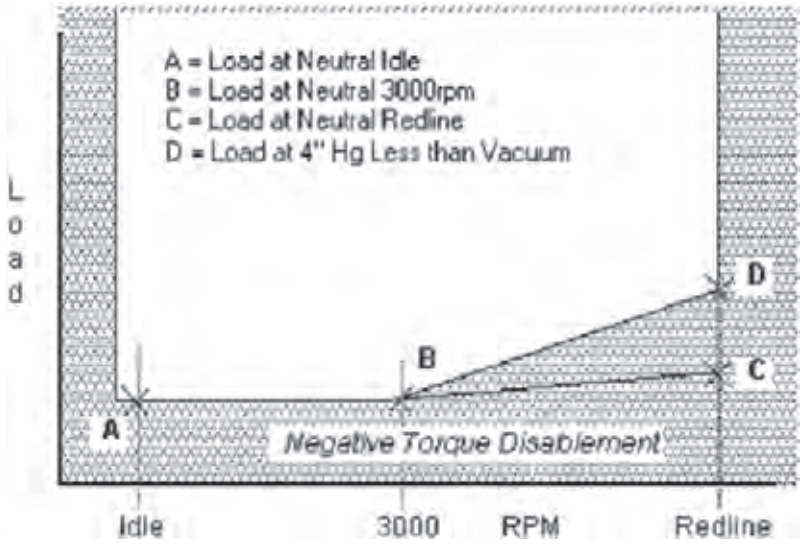


Figure 5.17 Misfire enablement window (Ford Motor Company)

the region of 1000 °C. The catalyst itself is a very expensive service item whether replaced by the customer or the manufacturer under warranty.

The misfire monitor is responsible for determining when misfire has occurred, calculating the rate of engine misfire and then initiating some kind of protective action in order to prevent catalyst damage.

The misfire monitor is in operation continuously within a 'calibrateable' engine speed/load window defined by the legislation. The United States requires misfire monitoring throughout the revs range but European legislation requires monitoring only up to 4500 rpm (Figure 5.17).

The crankshaft sensor generates a signal as the wheel rotates and the microprocessor processes this signal to determine the angular acceleration of the crankshaft produced by each engine cylinder when a firing event occurs. When a misfire occurs, the crankshaft decelerates and a cam position sensor identifies the cylinder that misfired.

Processing of the signal from the crank position sensor is not straightforward. A considerable amount of post-processing takes place to filter the signal and disable monitoring in unfavourable conditions. The misfire monitor must learn and cater for the differences in manufacturing tolerances of the crankshaft wheel and so has a specific sub-algorithm for learning these differences and allowing for them when calculating the angular acceleration of the crankshaft (Figure 5.18). These correction factors are calculated during deceleration, with the injectors switched off. They should be re-learned following driveline component changes such as flywheel, torque converter, crankshaft sensor, etc.

The misfire monitor must be able to detect two types of misfire:

- Type A misfire
- Type B misfire.

A type A misfire is defined as that rate of misfire, which causes catalyst damage. When this occurs, the MI will flash at a rate of 1 Hz and is allowed to stop flashing should the misfire disappear. The MI will stay on steady state should the misfire re-occur on a subsequent drive and the engine operating conditions are 'similar', that is, engine speed is within 375 rpm, engine load is within 20% and

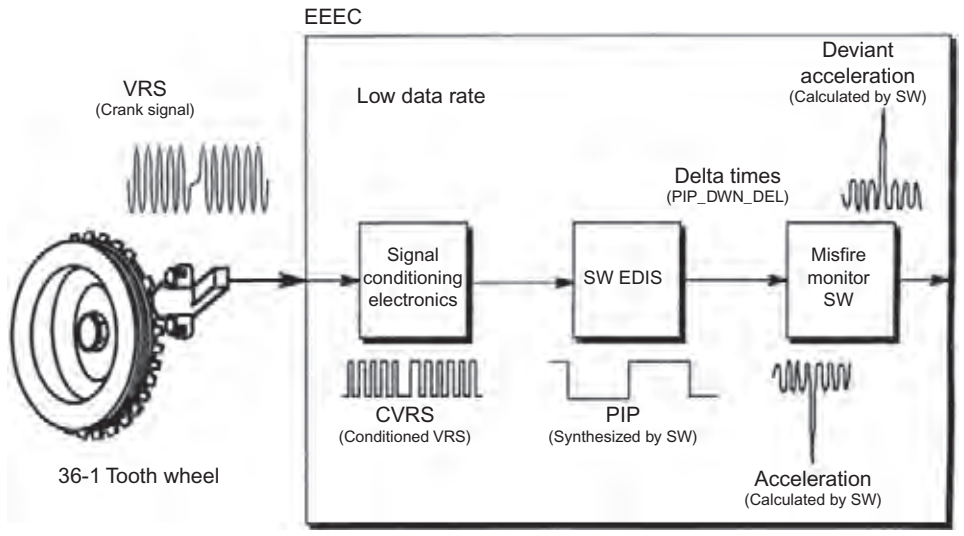


Figure 5.18 Crankshaft mounted wheel and sensor source of angular acceleration (Source: Ford Motor Company)

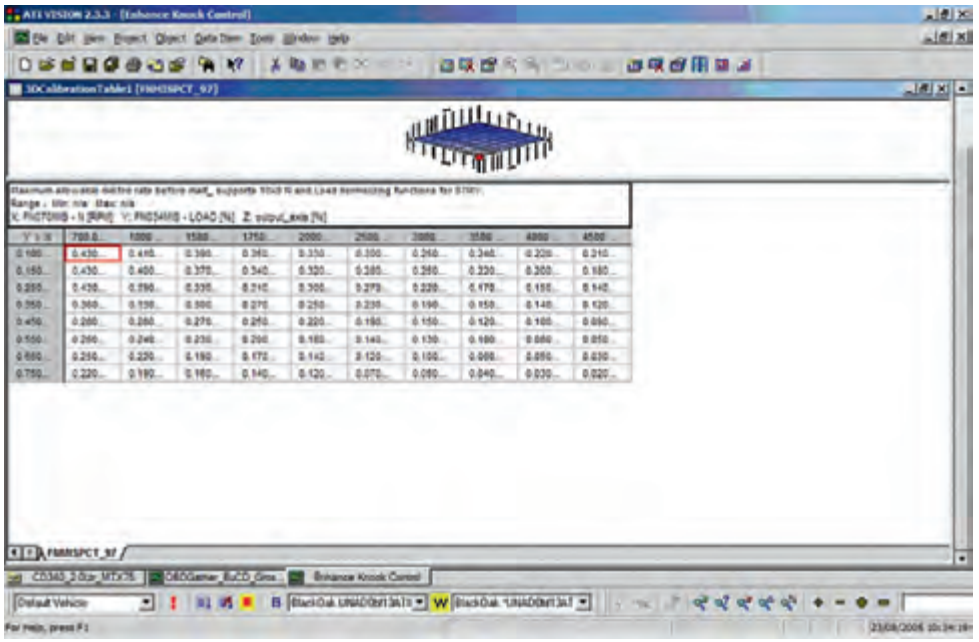


Figure 5.19 System development screen showing type A misfire rates normalised by engine speed and load (Source: Ford Motor Company)

the engine's warm-up status is the same as that under which the malfunction was first detected (and no new malfunctions have been detected).

The rate of misfire that will cause catalyst damage varies as a function of engine speed and load. Misfire rates in the region of 45% are required to damage a catalyst at neutral idle, while at 80% engine load and 4000 rpm, misfire rates in the region of only 5% are needed (Figure 5.19).

A type B misfire is defined as that rate of misfire which will cause the tailpipe emissions to exceed legislated levels. This varies from vehicle to vehicle and is dependent upon catalyst package. MI operation is the same as for standard DTCs.

The above is the most common method but misf res can be detected in a number of different ways as outlined in the following sections.

5.4.2 Crank speed f uctuation

A misf re event in a cylinder results in a lost power stroke. The gap in the torque output of the engine and a consequential momentary deceleration of the crankshaft can be detected using the crankshaft position sensor. By closely monitoring the speed and acceleration of the crankshaft, misf ring cylinders can be detected; this technology is very commonly used in OBD systems to detect non-f ring cylinders that can cause harmful emissions and catalyst damage (Figure 5.20).

There are a number of technical challenges that have to be overcome with this technique, the accuracy achieved and reliability of the system is very dependent on the algorithms used for signal processing and analysis. Under certain conditions, misf re detection can be diff cult, particularly at light load with high engine speed. Under these conditions, the damping of f ring pulses is low due to the light engine load, and this creates high momentary accelerations and decelerations of the crankshaft. This causes speed variation which can be mistakenly taken by the OBD system as a misf re. With this method of misf re detection, careful calibration of the OBD system is necessary to avoid false detection. Another vehicle operation mode which can cause problems is operation of the vehicle on rough or poorly made roads. This also causes rapid crankshaft oscillation that could activate false triggers, and under these conditions the misf re detection must be disabled.

5.4.3 Ionising current monitoring

An ionisation current sensing ignition system consists of one ignition coil per cylinder, normally mounted directly above the spark plug. Eliminating the

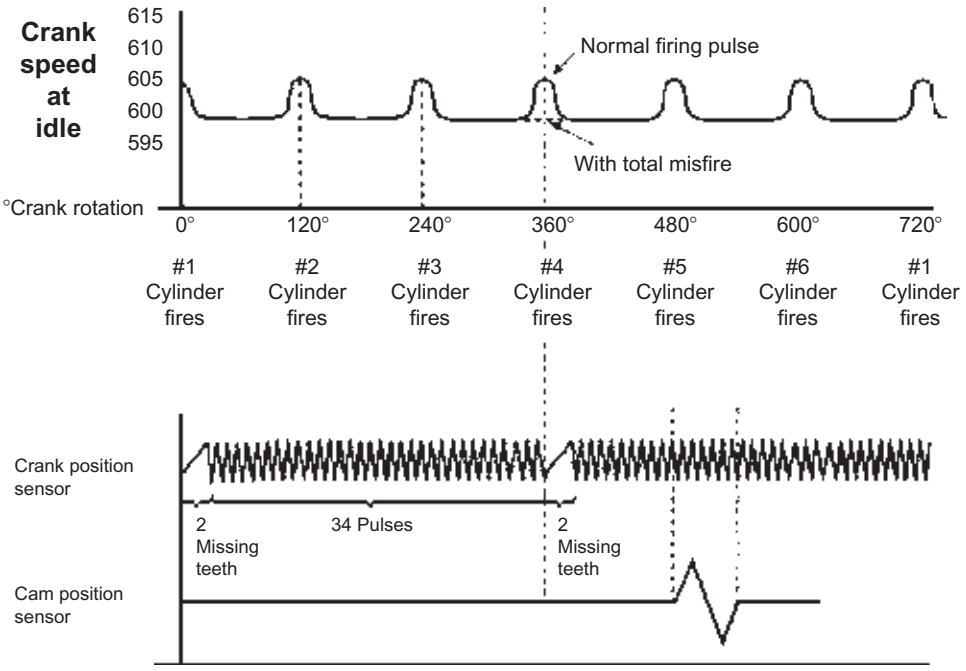


Figure 5.20 Misf re detection via crank sensor

distributor and high-voltage leads helps promote maximum energy transfer to the spark plug to ignite the mixture. In this system, the spark plug is not only used as a device to ignite the air/fuel mixture but is also used as an in-cylinder sensor to monitor the combustion process. The operating principle used in this technology is that an electrical current f ow in an ionised gas is proportional to the f ame electrical conductivity. By placing a direct current bias across the spark plug electrodes, the conductivity can be measured. The spark current is used to create this bias voltage and this eliminates the requirement for any additional voltage source.

The ion current is monitored, and if no ion-generating f ame is produced by the spark, no current f ows through the measurement circuit during the working part of the cycle. The ion current versus time trace is very different from that of a cycle when normal combustion occurs, and this information can be used as a differentiator to detect misf re from normal combustion. This method has proven to be very effective at monitoring for misf res under test conditions and also in practice.

The signal the system produces contains misf re information and, in addition, can provide objective knock or detonation information. This can be used for engine control systems where knowledge of the actual combustion process is required (as mentioned above) (Figures 5.21 and 5.22).

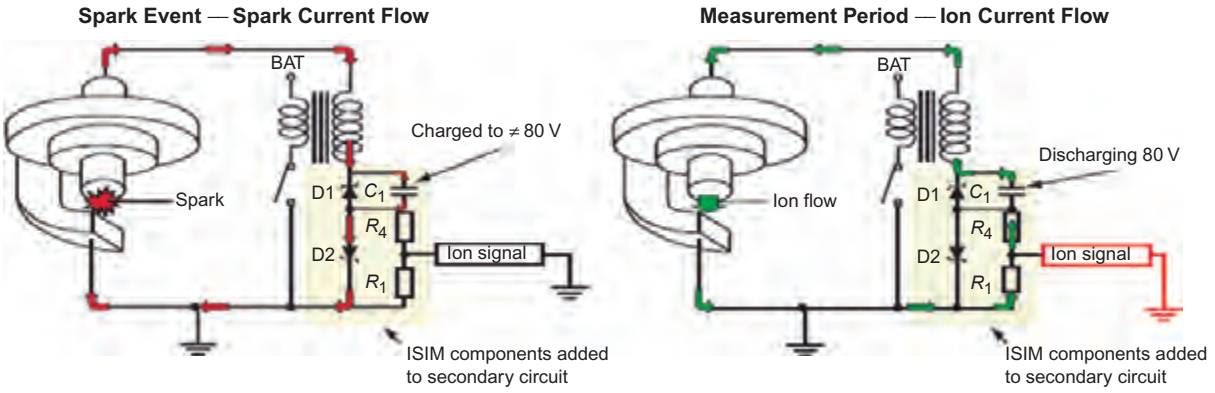


Figure 5.21 Ion-sensing circuit in direct ignition system

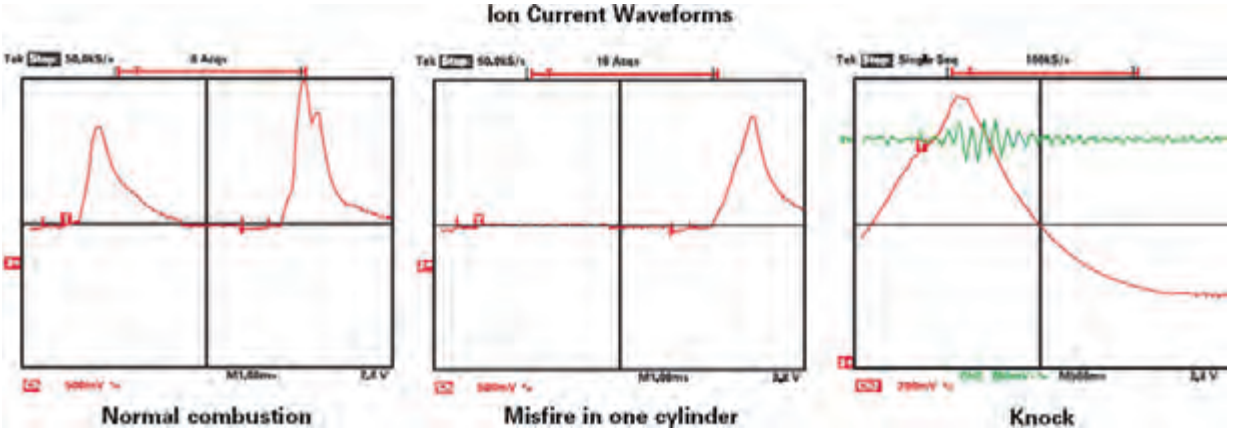


Figure 5.22 Resulting waveforms from the ion-sensing system



Figure 5.23 Cylinder pressure sensor mounted in the engine

5.4.4 Cylinder pressure sensing

This technology has great potential not just for OBD applications but also for additional feedback to the engine-management system about the combustion process due to the direct measurement technique (Figure 5.23). This additional control dimension can be utilised to improve engine performance and reduce emissions further. With respect to misf re detection, this method provides reliable detection of a positive combustion event and can easily detect misf re with utmost reliability.

The major drawback is the availability of suitable sensors that could be installed into the engine at production and would be durable enough to last the life of the engine and provide the required performance expected of sensors in an OBD system. For certain engine applications, sensors are available, and currently combustion sensor technology is under rapid development such that this technical hurdle will soon be overcome.

5.4.5 Exhaust pressure analysis

This solution involves using a pressure sensor in exhaust manifold combined with a Fourier analysis as the f rst stage of the signal processing. Using a sensor to analyse the gas pulses in the exhaust manifold, it is possible to detect single misf res, and additionally, it is possible to identify which cylinder is misf ring. This method is less intrusive than the above and could potentially be retrof tted at the production stage. A sensor in the exhaust can detect misf ring cylinders but cannot give useful, qualitative information about the combustion process. This technique has been demonstrated as capable of detecting all misf res at engine speeds up to 6000 rpm, for all engine conf gurations, loads and fuels. Generally, a ceramic capacitive–type sensor has been employed, which has a short response time and good durability.

5.5 OBD summary

OBD monitoring applies to systems which are most likely to cause an increase in harmful exhaust emission, namely

- all main engine sensors;
- fuel system;
- ignition system;
- EGR system.

The system uses information from sensors to judge the performance of the emission controls, but these sensors do not directly measure the vehicle emissions.

An important part of the system, and the main driver information interface, is the ‘check engine’ warning light, also known as the MIL. This is the main source of feedback to the driver to indicate if an engine problem has occurred or is present. When a malfunction or fault occurs, the warning light illuminates to alert the driver. Additionally, the fault is stored in the ECU memory. If normal condition is reinstated, the light extinguishes but the fault remains logged to aid diagnostics. Circuits are monitored for open or short circuits as well as plausibility. When a malfunction is detected, information about the malfunctioning component is stored.

An additional benef t allows the diagnostic technician to be able to access fault information and monitor engine performance via data streamed directly from the ECU while the engine is running (on certain vehicles). This information can be accessed via various scan tools available on the market and is communicated in a standardised format, so one tool (more or less!) works with all vehicles. The data is transmitted in a digital form via this serial interface. Thus, data values are transmitted as data words and the protocol used for this data stream has to be known in order to evaluate the information properly.

The benef ts of having an OBD system are that it

- encourages vehicle and engine manufacturers to have a responsible attitude to reducing harmful emissions from their engines via the development of reliable and durable emission control systems;
- aids diagnosis and repair of complex electronic engine and vehicle control systems;
- reduces global emissions by identifying and highlighting immediately to the driver or user emission control systems in need of repair;
- provides 'whole life' emission control of the engine.

On-board diagnostics, or OBD, was the name given to the early emission control and engine-management systems introduced in cars. There was no single standard – each manufacturer often uses quite different systems (even between individual car models). OBD systems have been developed and enhanced, in line with United States government requirements, into the current OBD2 standard. The OBD2 requirement applies to all cars sold in the United States from 1996. EOBD is the European equivalent of the American OBD2 standard, which applies to petrol cars sold in Europe from 2001 (and diesel cars three years later).

Key fact

OBD2 (also OBDII) was developed to address the shortcomings of OBD1 and make the system more user friendly for service and repair technicians.

5.5.1 OBD2

Even though new vehicles sold today are cleaner than they have ever been, the millions of cars on the road and the ever-increasing miles they travel each day make them our single greatest source of harmful emissions. While a new vehicle may start out with very low emissions, infrequent maintenance or failure of components can cause the vehicle emission levels to increase at an undesirable rate. OBD2 works to ensure that the vehicles remain as clean as possible over their entire life. The main features of OBD2 are, therefore, as follows:

- malfunction of emission relevant components to be detected when emission threshold values are exceeded;
- storage of failures and boundary conditions in the vehicle's fault memory;
- diagnostic light (MIL) to be activated in case of failures;
- read out of failures with generic scan tool.

The increased power of micro controllers (CPUs) in ECUs has meant that a number of important developments could be added with the introduction of OBD2. These include catalyst eff ciency monitoring, misf re detection, canister purge and EGR f ow rate monitoring. An additional benef t was the standardisation of diagnostic equipment interfaces.

For OBD1, each manufacturer applied specif c protocols. With the introduction of OBD2, a standardised interface was developed with a standard connector for all vehicles, and a standardised theory for fault codes relating to the engine and powertrain (more about this later). This meant that generic scan tools could

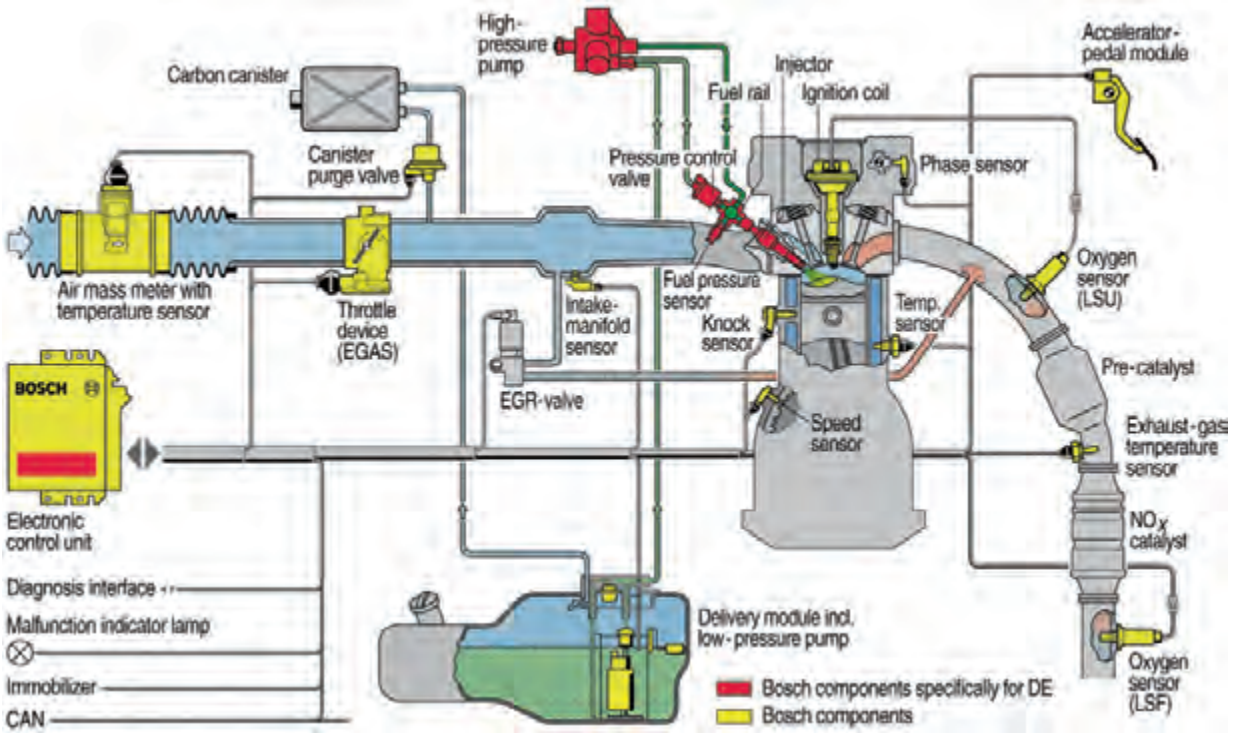


Figure 5.24 OBD2 system showing the main components of a gasoline direct injection system (Source: Bosch Media)

be developed and used in the repair industry by diagnostic technicians to aid troubleshooting of vehicle problems.

Another feature of OBD2 is that the prescribed thresholds at which a fault is deemed to have occurred are in relation to regulated emission limits. The basic monitor function is as follows:

- Monitoring of catalyst eff ciency, engine misf re and oxygen sensors function such that crossing a threshold of 1.5 times the emission limit will record a fault.
- Monitoring of the evaporation control system such that a leak greater than the equivalent leak from a 0.04 inch hole will record a fault.

The main features of an OBD2 compliant system (as compared to OBD1) are as follows (Figure 5.24):

- pre- and post-catalyst oxygen sensors to monitor conversion eff ciency;
- much more powerful ECU with 32 bit processor;
- ECU map data held on EEPROMS such that they can be accessed and manipulated via an external link; no need to remove ECU from vehicle for software updates or tuning;
- more sophisticated EVAP system, can detect minute losses of fuel vapour;
- EGR systems with feedback of position/f ow rate;
- sequential fuel injection with MAP and MAF sensing for engine load.

5.5.2 EOBD

EOBD is an abbreviation of European on-board diagnostics. All petrol/gasoline cars sold in Europe since 1 January 2001, and diesel cars manufactured from 2003, must have OBD systems to monitor engine emissions. These systems were introduced in line with European directives to monitor and reduce emissions

from cars. All such cars must also have a standard EOBD diagnostic socket that provides access to this system. The EOBD standard is similar to the US OBD2 standard. In Japan, the JOBD system is used. The implementation plan for EOBD was as follows:

- January 2000 OBD for all new petrol/gasoline vehicle models
- January 2001 OBD for all new petrol/gasoline vehicles
- January 2003 OBD for all new diesel vehicle models PC/LDV
- January 2004 OBD for all new diesel vehicles PC/LDV
- January 2005 OBD for all new diesel vehicles HDV.

The EOBD system is designed, constructed and installed in a vehicle such as to enable it to identify types of deterioration or malfunction over the entire life of the vehicle. The system must be designed, constructed and installed in a vehicle to enable it to comply with the requirements during conditions of normal use.

In addition, EOBD and OBD2 allow access to manufacturer-specif c features available on some OBD2/EOBD compliant scan tools. This allows additional parameters or information to be extracted from the vehicle systems. These are in addition to the normal parameters and information available within the EOBD/OBD2 standard. These enhanced functions are highly specif c and vary widely between manufacturers.

The monitoring capabilities of the EOBD system are def ned for petrol/gasoline (spark ignition) and diesel (compression ignition) engines. The following is an outline:

Spark ignition engines

- Detection of the reduction in the eff ciency of the catalytic converter with respect to emissions of HC only.
- The presence of engine misf res in the engine operation region within the following boundary conditions.
- Oxygen sensor deterioration.
- Other emission control system components or systems, or emission-related powertrain components or systems which are connected to a computer, the failure of which may result in tailpipe emission exceeding the specif ed limits.
- Any other emission-related powertrain component connected to a computer must be monitored for circuit continuity.
- The electronic evaporative emission purge control must, at a minimum, be monitored for circuit continuity.

Compression ignition engines

- Where f tted, reduction in the eff ciency of the catalytic converter.
- Where f tted, the functionality and integrity of the particulate trap.
- The fuel injection system electronic fuel quantity and timing actuator(s) is/are monitored for circuit continuity and total function failure.
- Other emission control system components or systems, or emission-related powertrain components or systems which are connected to a computer, the failure of which may result in tailpipe emission exceeding the specif ed limits given. Examples of such systems or components are those for monitoring and control of air mass f ow, air volumetric f ow (and temperature), boost pressure and inlet manifold pressure (and relevant sensors to enable these functions to be carried out).
- Any other emission-related powertrain component connected to a computer must be monitored for circuit continuity (Table 5.3).

Def nition

EOBD: European on-board diagnostics.

Table 5.3 Emission limits table for comparison

Legislation	OBD malfunction limit (g/km)			
	HC	CO	NO_x	PM
EPA	≥1.5 times the applicable federal standard			
EPA – method	Multiplicative relative to limits			
CARB 1 and 2	≥1.5 times the relevant CARB emission limits			
CARB 1 and 2 – metho	Multiplicative relative to limits			
EOBD positive ign. 2000	0.40	3.20	0.60	–
EOBD diesel 2003	0.40	3.20	1.20	0.18
EOBD positive ign. 2005	0.20	1.40	0.30	–
EOBD diesel 2008 (for indication only)	0.30	2.40	0.90	0.14
EOBD – method	Absolute limits			

5.5.3 Features and technology of current systems

To avoid false detection, the legislation allows verif cation and healing strategies. These are outlined as follows:

MIL activation logic for detected malfunctions

To avoid wrong detections, the legislation allows verif cation of the detected failure. The failure is stored in the fault memory as a pending code immediately after the f rst recognition but the MIL is not activated. The MIL will be illuminated in the third driving cycle, in which the failure has been detected; the failure is then recognised as a conf rmed fault.

MIL healing

The MIL may be deactivated after three subsequent sequential driving cycles during which the monitoring system responsible for activating the MIL ceases to detect the malfunction, and if no other malfunction has been identif ed that would independently activate the MIL.

Healing of the fault memory

The OBD system may erase a fault code, distance travelled and freeze frame information if the same fault is not re-registered in at least 40 engine warm-up cycles.

Freeze frame

This is a feature that can assist in the diagnosis of intermittent faults. Upon determination of the f rst malfunction of any component or system, ‘freeze frame’ engine conditions present at the time must be stored in the computer memory. Stored engine conditions must include, but are not limited to,

- calculated/derived load value;
- engine speed;
- fuel trim values (if available);
- fuel pressure (if available);
- vehicle speed (if available);

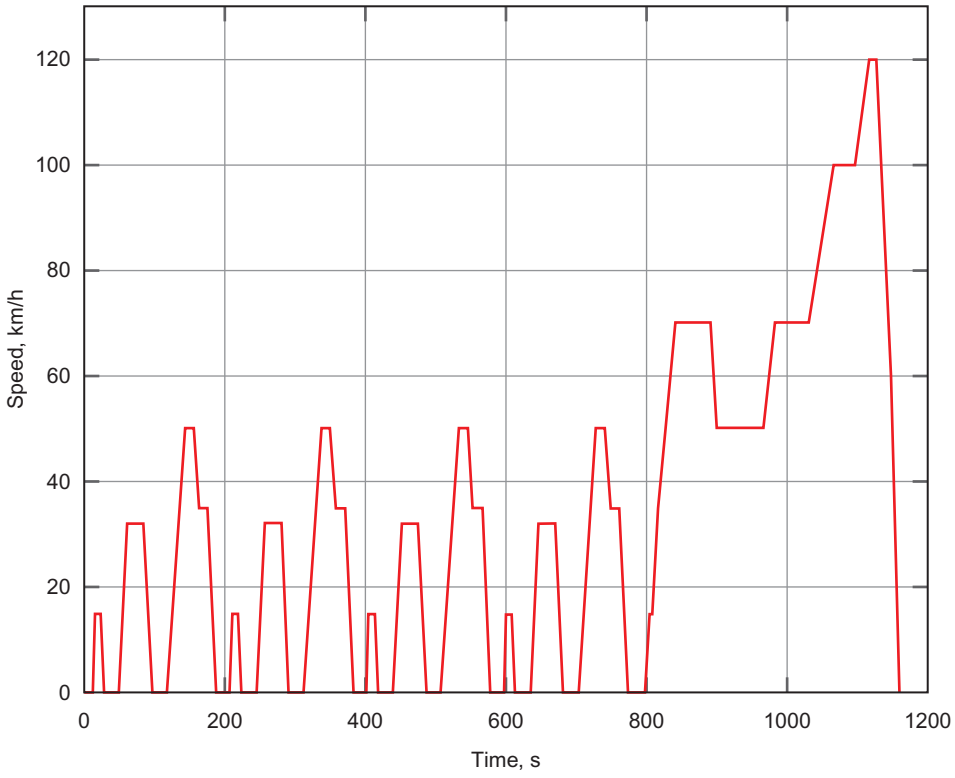


Figure 5.25 New European Driving Cycle (NEDC)

- coolant temperature;
- intake manifold pressure (if available);
- closed or open-loop operation (if available);
- the fault code which caused the data to be stored.

5.6 Driving cycles

5.6.1 Introduction

Even before a vehicle is subjected to OBD systems, it must pass stringent emissions tests. This is done by running the vehicle through test cycles and collecting the exhaust for analysis.

5.6.2 Europe

The New European Driving Cycle (NEDC) is a driving cycle consisting of four repeated ECE-15 driving cycles and an extra-urban driving cycle (EUDC). The NEDC is meant to represent the typical usage of a car in Europe, and is used, among other things, to measure emissions (Figure 5.25). It is sometimes referred to as MVEG (Motor Vehicle Emissions Group) cycle.

The *old* European ECE-15 driving cycle lies between 0 and 800 seconds and represented an urban drive cycle. The section from 800 seconds represents a sub-urban drive cycle, and is now called the New European Driving Cycle.

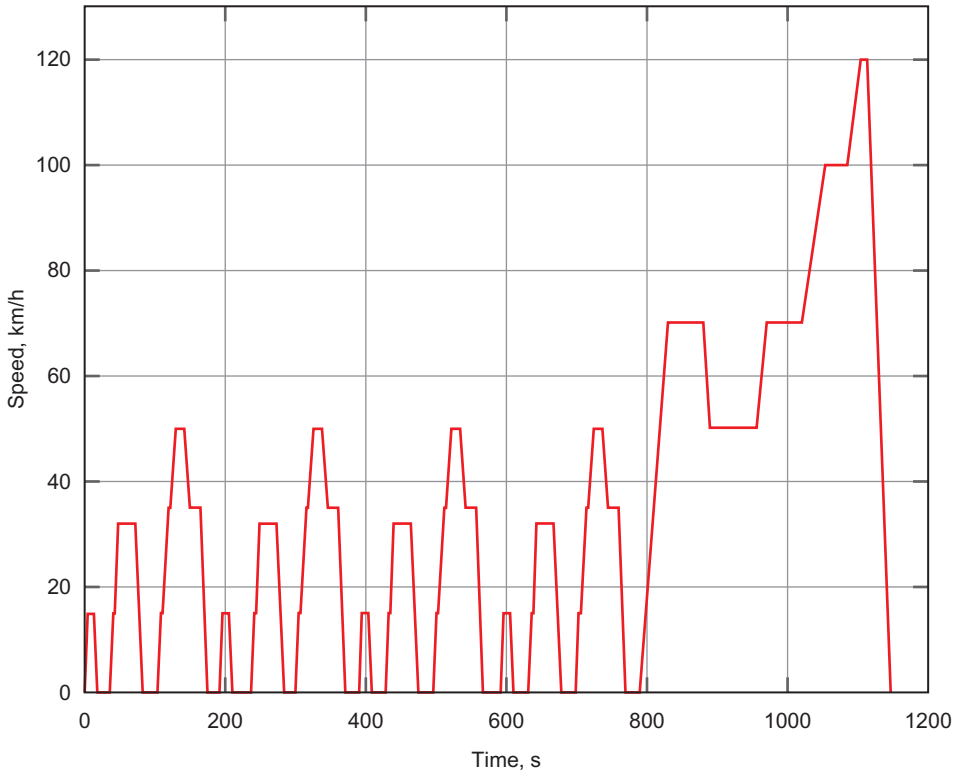


Figure 5.26 Modified New European Driving Cycle (MNEDC)

The cycle must be performed on a cold vehicle at 20 °C (68 °F). The cycles may be performed on a normal flat road, in the absence of wind. However, to improve repeatability, they are generally performed on a rolling road.

Several measurements are usually performed during the cycle. The figures made available to the general public are the following:

- urban fuel economy (first 800 seconds);
- extra-urban fuel economy (800–1200 seconds);
- overall fuel economy (complete cycle);
- CO_2 emission (complete cycle);

The following parameters are also generally measured to validate the compliance to European emission standards:

- carbon monoxide (CO);
- unburnt hydrocarbons (HC);
- nitrogen oxides (NO_x);
- particulate matter (PM).

A further tightening of the driving cycle is the Modified New European Driving Cycle (MNEDC), which is very similar to the NEDC except that there is no warm-up time at the start (Figure 5.26).

5.6.3 United States

In the United States, a cycle known as the Federal Test Procedure FTP-75 is used. This has been added to and became known as the Supplementary Federal Test Procedure (SFTP) (Figure 5.27).

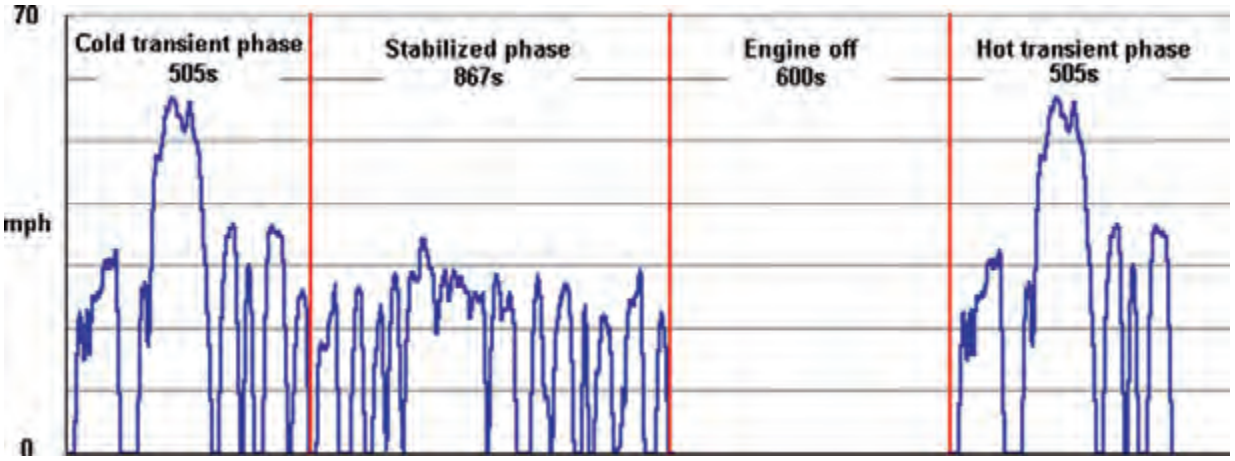


Figure 5.27 US Federal Test Procedure

5.7 Future developments in diagnostic systems

5.7.1 OBD3

Key fact

OBD3 may take OBD2 further by adding remote data transfer

The current generation of OBD is a very sophisticated and capable system for detecting emissions problems. However, it is necessary to get the driver of the vehicle to do something about the problem. With respect to this aspect, OBD2/EOBD is no improvement over OBD1 unless there is some enforcement capability. Plans for OBD3 have been under consideration for some time now. The idea being to take OBD2 a step further by adding remote data transfer.

An OBD3 equipped vehicle would be able to report emissions problems directly back to a regulatory authority. The transmitter, which will be similar to those currently used for automatic toll payments, would communicate the vehicle identification number (VIN) and any diagnostic codes that have been logged. The system could be set up to automatically report an emissions problem the instant the MIL light is on, or alternatively, the system could respond to answer a query about its current emissions performance status. It could also respond via a cellular or satellite link, reporting its position at the same time.

While somewhat 'Big Brother', this approach is very efficient. The need for periodic inspections could be eliminated because only those vehicles that reported problems would have to be tested. The regulatory authorities could focus their efforts on vehicles and owners who are actually causing a violation rather than just random testing. It is clear that with a system like this, much more efficient use of available regulatory enforcement resources could be implemented, with a consequential improvement in air quality.

An inevitable change that could come with OBD3 would be even closer scrutiny of vehicle emissions. The misfire detection algorithms currently required by OBD2 only look for misfires during driving conditions that occur during the prescribed driving cycles. It does not monitor misfires during other engine operating modes, like full load. More sophisticated methods of misfire detection (as discussed in Chapter 4) will become common place. These systems can feedback other information to the ECU about the combustion process, for example, the maximum cylinder pressure, detonation events or work done via an indicated mean effective pressure (IMEP) calculation. This adds another dimension to the

engine control system allowing greater eff ciency and more power from any given engine design by just using more sophisticated ECU control strategy.

Future OBD system will undoubtedly incorporate new developments in sensor technology. Currently, the evaluation is done via sensors monitoring emissions indirectly. Clearly an improvement would be the ability to measure exhaust gas composition directly via on-board measurement (OBM) systems. This is more in keeping with emission regulation philosophy and would overcome the inherent weakness of current OBD systems, that is, they fail to detect a number of minor faults that do not individually activate the MIL or cause excessive emissions but whose combined effect is to cause the production of excess emissions.

The main barrier is the lack of availability of suitably durable and sensitive sensors for CO, NO_x and HC. Some progress has been made with respect to this, and some vehicles are now being f tted with NO_x sensors. Currently, there does appear to be a gap between the laboratory-based sensors used in research and reliable mass produced units that could form the basis of an OBM system. The integration of combustion measurement in production vehicles produces a similar problem.

5.7.2 Diesel engines

Another development for future consideration is the further implementation of OBD for diesel engines. As diesel engine technology becomes more sophisticated, so does the requirement for OBD. In addition, emission legislation is driving more sophisticated requirements for after-treatment of exhaust gas. All of these sub-systems are to be subjected to checking via the OBD system and present their own specif c challenges; for example, the monitoring of exhaust after-treatment systems (particulate f lters and catalysts) in addition to more complex EGR and air management systems.

5.7.3 Rate-based monitoring

Rate-based monitoring will be more signif cant for future systems which allow in-use performance ratio information to be logged. It is a standardised method of measuring monitoring frequency and f lters out the effect of short trips, infrequent journeys, etc. as factors which could affect the OBD logging and reactions. It is an essential part of the evaluation where driving habits or patterns are not known and it ensures that monitors run eff ciently in use and detect faults in a timely and appropriate manner. It is def ned as

$$\text{Minimum frequency} = \frac{N}{D}$$

where N = number of times a monitor has run and D = number of times the vehicle has been operated.

5.7.4 Model-based development

A signif cant factor in the development of future systems will be the implementation of the latest technologies with respect to hardware and software development. Model-based development and calibration of system will dramatically reduce the testing time by reducing the number of test iterations

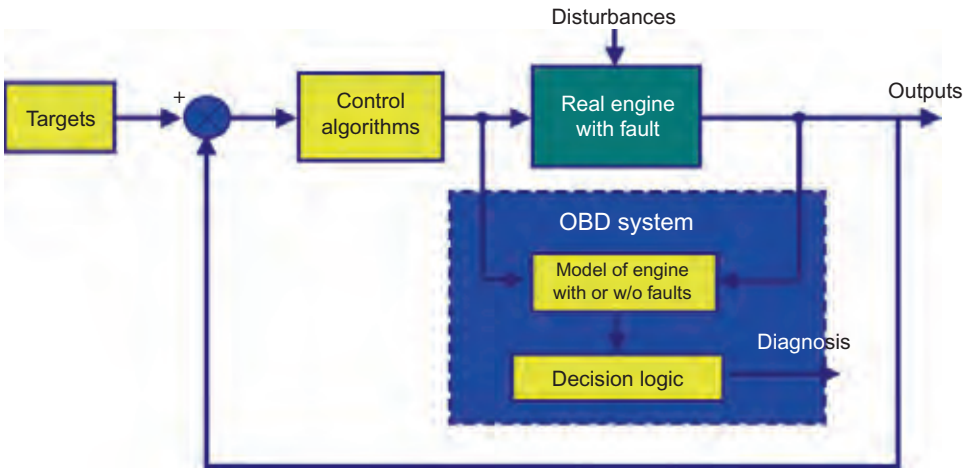


Figure 5.28 Model-based calibration of OBD system

required. This technique is quite common for developing engine-specif c calibrations for ECUs during the engine development phase (Figure 5.28).

Hardware-in-loop (HIL) simulation plays a part in rapid development of any hardware. New hardware can be tested and validated under a number of simulated conditions, and its performance verif ed before it even goes near any prototype vehicle. The following tasks can be performed with this technology:

- full automation of testing for OBD functionality;
- testing of parameter extremes;
- testing of experimental designs;
- regression testing of new designs of software and hardware;
- automatic documentation of results.

5.8 Summary

Clearly, OBD is here to stay and will continue to be developed. It is a useful tool for the technician as well as a key driver towards cleaner vehicles. The creation of generic standards has helped those of us at the 'sharp end' of diagnostics signif cantly.

OBD has a number of key emission-related systems to 'monitor'. It saves faults in these systems in a standard form so that they can be accessed using a scan tool.

However, with the possibility of OBD3 using the navigation system to report where we are, speed and traff c light cameras everywhere and monitoring systems informing the authorities about the condition of our vehicles, whatever will be next?

Acknowledgement

I am most grateful to Dave Rogers (http://www.autoelex.co.uk) and Alan Malby (Ford Motor Company) for their excellent contributions to this chapter.

CHAPTER

Engine systems

6.1 Introduction

The main sections in this chapter that relate to an area of the vehicle start with an explanation of the particular system. The sections then conclude with appropriate diagnostic techniques and symptom charts. Extra tests and methods are explained where necessary.

6.2 Engine operation

6.2.1 Four-stroke cycle

Figure 6.1 shows a modern vehicle engine. Engines like this can seem very complex at f rst but keep in mind when carrying out diagnostic work that, with very few exceptions, all engines operate on the four-stroke principle. The complexity lies in the systems around the engine to make it operate to its



Figure 6.1 Ford Focus engine (Source: Ford Media)

Advanced Automotive Fault Diagnosis.
© 2012 Tom Denton. Published by Routledge. All rights reserved.

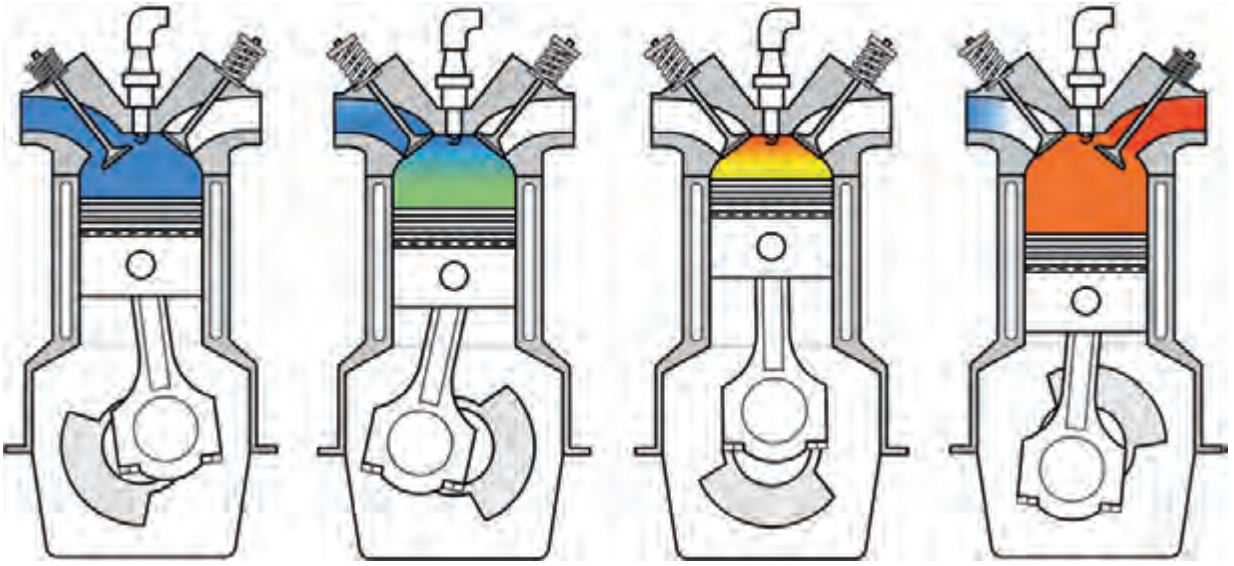


Figure 6.2 Four-stroke cycle: induction, compression, power and exhaust

Key fact

Stroke means the movement of a piston from top dead centre (TDC) to bottom dead centre (BDC) or the other way round.

maximum eff ciency or best performance. With this in mind then, back to basics: The engine components are combined to use the power of expanding gas to drive the engine.

When the term 'stroke' is used, it means the movement of a piston from top dead centre (TDC) to bottom dead centre (BDC) or the other way round. The following table explains the spark ignition (SI) and compression ignition (CI) four-stroke cycles – for revision purposes. Figure 6.2 shows the SI cycle.

Stroke	Spark ignition	Compression ignition
Induction	The fuel air mixture is forced into the cylinder through the open inlet valve because as the piston moves down, it makes a lower pressure. It is acceptable to say the mixture is drawn into the cylinder	Air is forced into the cylinder through the open inlet valve because as the piston moves down, it makes a lower pressure. It is acceptable to say the air is drawn into the cylinder
Compression	As the piston moves back up the cylinder, the fuel air mixture is compressed to about an eighth of its original volume because the inlet and exhaust valves are closed. This is a compression ratio of 8:1, which is typical for many normal engines	As the piston moves back up the cylinder, the fuel air mixture is compressed in some engines to about a sixteenth of its original volume because the inlet and exhaust valves are closed. This is a compression ratio of 16:1, which causes a large build-up of heat
Power	At a suitable time before TDC, a spark at the plug ignites the compressed mixture. The mixture now burns very quickly and the powerful expansion pushes the piston back down the cylinder. Both valves are closed	At a suitable time before TDC, very high pressure atomised diesel fuel (at approximately 180 bar) is injected into the combustion chamber. The mixture burns very quickly and the powerful expansion pushes the piston back down the cylinder. The valves are closed
Exhaust	The final stroke occurs as the piston moves back up the cylinder and pushes the spent gases out of the now open exhaust valve	The final stroke occurs as the piston moves back up the cylinder and pushes the spent gases out of the now open exhaust valve

6.2.2 Cylinder layouts

Great improvements can be made to the performance and balance of an engine by using more than one cylinder. Once this is agreed, the actual layout of the cylinders must be considered. The layout can be one of three possibilities as follows:

- **In-line or straight** – The cylinders are in a straight line. They can be vertical, inclined or horizontal.
- **Vee** – The cylinders are in two rows at a set angle. The actual angle varies but is often 60° or 90°.
- **Opposed** – The cylinders are in two rows opposing each other and are usually horizontal.

By far the most common arrangement is the straight four, and this is used by all manufacturers in their standard family cars. Larger cars do, however, make use of the 'Vee' conf guration. The opposed layout although still used is less popular. Engine f ring order is important. This means the order in which the power strokes occur. It is important to check in the workshop manual or data book when working on a particular engine.

6.2.3 Camshaft drives

The engine drives the camshaft in one of three ways: gear drive, chain drive or by a drive belt. The last of these is now the most popular, as it tends to be simpler and quieter. Note in all cases that the cam is driven at half the engine speed. This is done by the ratio of teeth between the crank and cam cogs which is 1:2, for example 20 crank teeth and 40 cam teeth.

Key fact

A camshaft is driven at half the speed of the crankshaft.

- **Camshaft drive gears** – Gears are not used very often on petrol engines but are used on larger diesel engines. They ensure a good positive drive from the crankshaft gear to the camshaft.
- **Camshaft chain drive** – Chain drive is still used but was even more popular a few years ago. The problems with it are that a way must be found to tension the chain and also provide lubrication.
- **Camshaft drive belt** – Camshaft drive belts have become very popular. The main reasons for this are that they are quieter, do not need lubrication and are less complicated. They do break now and then, but this is usually due to lack of servicing. Cam belts should be renewed at set intervals. Figure 6.3 shows an example of the data available relating to camshaft drive belt f tting. This is one of the many areas where data is essential for diagnostic checks.

6.2.4 Valve mechanisms

A number of methods are used to operate the valves. Three common types are shown in Figure 6.4 and a basic explanation of each follows:

- Overhead valve with push rods and rockers – The method has been used for many years and although it is not used as much now, many vehicles still on the road are described as overhead valve (OHV). As the cam turns, it moves the follower, which in turn pushes the push rod. The push rod moves the rocker, which pivots on the rocker shaft and pushes the valve open. As the cam moves further, it allows the spring to close the valve.

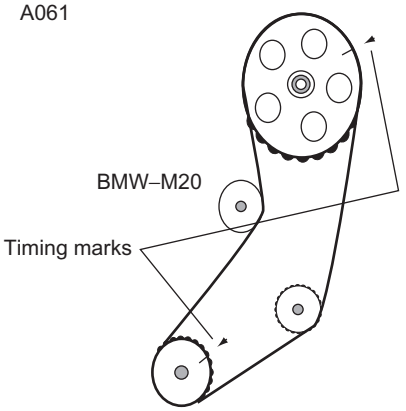
BMW 5 Series 2.5 525i SE
Timing belt
A061 
Replacement intervals: at 36 000 miles Engine setting position: TDC at No. 1 cylinder Special tools: Viscous coupling tool 11.5.040 Pulley retaining tool 11.5.030 Torque settings: Crank pulley 23 Nm Tensioner 23 Nm Fan coupling 43 Nm Special notes: The fan coupling has left hand thread. Set timing for camshaft and crankshaft and check TDC mark on the flywheel. Check for rotor arm alignment to distributor casing. After fitting belt, rotate engine two full turns and recheck the timing marks.

Figure 6.3 Timing belt data

- Overhead cam with followers – Using an overhead cam (OHC) reduces the number of moving parts. In the system shown here, the lobe of the cam acts directly on the follower which pivots on its adjuster and pushes the valve open.
- Overhead cam, direct acting and automatic adjusters – Most new engines now use an OHC with automatic adjustment. This saves on repair and service time and keeps the cost to the customer lower. Systems vary between manufacturers, some use followers and some have the cam acting directly on to the valve. In each case, though, the adjustment is by oil pressure. A type of plunger, which has a chamber where oil can be pumped under pressure, operates the valve. This expands the plunger and takes up any unwanted clearance.

Valve clearance adjustment is very important. If it is too large, the valves will not open fully and will be noisy. If the clearance is too small, the valves will not close and no compression will be possible. When an engine is running, the valves become very hot and therefore expand. The exhaust valve clearance is usually larger than the inlet, because it gets hotter. Regular servicing is vital for

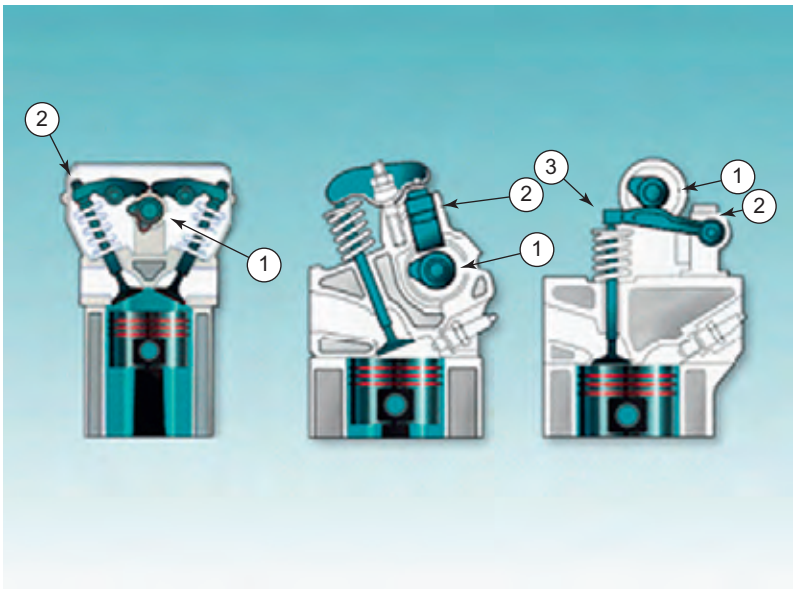


Figure 6.4 Valve operating mechanisms. Left: 1 – Cam; 2 – adjusting screw in direct acting rocker. Centre: 1 – Cam; 2 – hydraulic follower. Right: 1 – Cam; 2 – pivot and adjuster; 3 – f follower

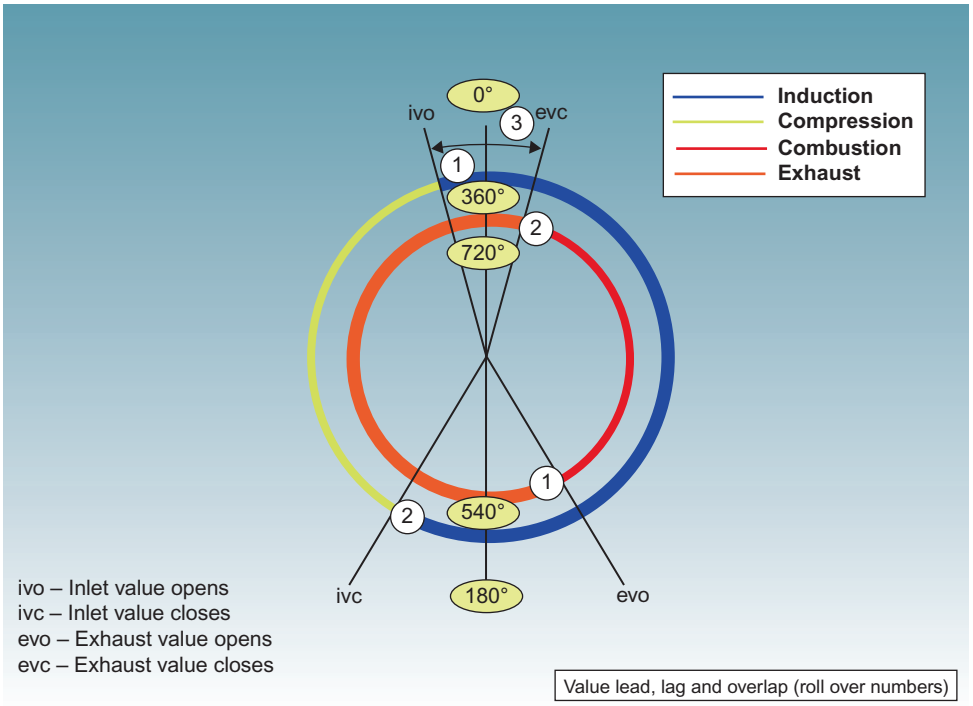


Figure 6.5 Valve timing diagrams (1 – lead; 2 – lag; 3 – overlap)

all components but, in particular, the valve operating mechanism needs a good supply of clean oil at all times.

6.2.5 Valve and ignition timing

Valve timing is important. The diagram in Figure 6.5 shows accurately the degrees of rotation of the crankshaft where the inlet and exhaust valves open

and close during the four-stroke cycle. The actual position in the cycle of operation when valves open and close depends on many factors and will vary slightly with different designs of engine. Some cars now control valve timing by electronics. The diagram is marked to show what is meant by valve lead, lag and overlap. Ignition timing is marked on the diagram. Note how this changes as engine speed changes.

The valve timing diagram shows that the valves of a four-stroke engine open just before and close just after the particular stroke. Looking at the timing diagram, if you start at position IVO, the piston is nearly at the top of the exhaust stroke when the inlet valve opens (IVO). The piston reaches the top and then moves down on the intake stroke. Just after starting the compression stroke, the inlet valve closes (IVC). The piston continues upwards and, at a point several degrees before TDC, the spark occurs and starts the mixture burning.

Key fact

Maximum expansion is 'timed' to occur after TDC on the power stroke.

The maximum expansion is 'timed' to occur after TDC; therefore, the piston is pushed down on its power stroke. Before the end of this stroke, the exhaust valve opens (EVO). Most of the exhaust gases now leave because of their very high pressure. The piston pushes the rest of the spent gases out as it moves back up the cylinder. The exhaust valve closes (EVC) just after the end of this stroke and the inlet has already opened, ready to start the cycle once again.

The reason for the valves opening and closing like this is that it makes the engine more eff cient by giving more time for the mixture to enter and the spent gases to leave. The outgoing exhaust gases in fact help to draw in the fuel air mixture from the inlet. Overall, this makes the engine have a better 'volumetric eff ciency'.

6.3 Diagnostics – engines

6.3.1 Systematic testing example

If the reported fault is excessive use of engine oil, proceed as follows:

1. Question the customer to f nd out how much oil is being used.
2. Examine the vehicle for oil leaks and blue smoke from the exhaust.
3. For example, oil may be leaking from a gasket or seal – if no leaks are found, the engine may be burning the oil.
4. A compression test, if the results were acceptable, would indicate a leak to be the most likely fault. Clean down the engine and run for a while, the leak might show up.
5. For example, change the gasket or seals.
6. Run a thorough inspection of vehicle systems, particularly those associated with the engine. Double check that the fault has been rectif ed and that you have not caused any other problems.

Safety f rst

Note: You should always refer to the manufacturer's instructions appropriate to the equipment you are using.

6.3.2 Test equipment

Compression tester

With this device the spark plugs are removed and the tester screwed or held in to each spark plug hole in turn. The engine is cranked over by the starter and the gauge will read the compression or pressure of each cylinder.



Figure 6.6 Diagnostic gauges

Table 6.1 Tests and information required

Test carried out	Information required
Compression test	Expected readings for the particular engine under test. For example, the pressure reach for each cylinder may be expected to read 80kPa ±15%
Cylinder leakage test	The percentage leak that is allowed for the tester you are using – some allow approximately 15% leakage as the limit

Cylinder leakage tester

A leakage tester uses compressed air to pressurise each cylinder in turn by a f tting to the spark plug hole. The cylinder under test is set to TDC compression. The percentage of air leaking out and where it is leaking from helps you determine the engine condition. For example, if air is leaking through the exhaust pipe, then the exhaust valves are not sealing. If air leaks into the cooling system, then a leak from the cylinder to the water jacket may be the problem (blown head gasket is possible). Figure 6.6 shows a selection of Snap-on diagnostic gauges – vacuum, compression and leakage.

6.3.3 Test results

Some of the information you may have to get from other sources such as data books or a workshop manual is listed in Table 6.1.

6.3.4 Engine fault diagnosis table 1

Symptom	Possible causes or faults	Suggested action
Oil consumption	Worn piston rings and/or cylinders Worn valve stems, guides or stem oil seals	Engine overhaul Replace valves (guides if possible) and oil seals
Oil on engine or floor	Leaking gaskets or seals Build-up of pressure in the crankcase	Replace appropriate gasket or seal Check engine breather system
Mechanical knocking noises	Worn engine bearings (big ends or mains for example) Incorrect valve clearances or defective automatic adjuster Piston slap on side of cylinder	Replace bearings or overhaul engine, good idea to also check the oil pressure Adjust clearances to correct settings or replace defective adjuster Engine overhaul required now or quite soon
Vibration	Engine mountings loose or worn Misfiring	Secure or renew Check engine ancillary systems such as fuel and ignition

6.3.5 Engine fault diagnosis table 2

Please note that this section covers related engine systems as well as the engine itself.

Symptom	Possible cause
Engine does not rotate when trying to start	Battery connection loose or corroded Battery discharged or faulty Broken, loose or disconnected wiring in the starter circuit Defective starter switch or automatic gearbox inhibitor switch Starter pinion or flywheel ring gear loose Earth strap broken, loose or corroded
Engine rotates but does not start	No fuel in the tank! Discharged battery (slow rotation) Battery terminals loose or corroded Air filter dirty or blocked Low cylinder compressions Broken timing belt Damp ignition components Fuel system fault Spark plugs worn to excess Ignition system open circuit
Difficult to start when cold	Discharged battery (slow rotation) Battery terminals loose or corroded Air filter dirty or blocked Low cylinder compressions Fuel system fault Spark plugs worn to excess Enrichment device not working (choke or injection circuit)
Difficult to start when hot	Discharged battery (slow rotation) Battery terminals loose or corroded Air filter dirty or blocked Low cylinder compressions Fuel system fault

(*Continued*)

Symptom	Possible cause
Starter noisy	Starter pinion or flywheel ring gear loose Starter mounting bolts loose Starter worn (bearings, etc.) Discharged battery (starter may jump in and out)
Starter turns engine slowly	Discharged battery (slow rotation) Battery terminals loose or corroded Earth strap or starter supply loose or disconnected Internal starter fault
Engine starts but then stops immediately	Ignition wiring connection intermittent Fuel system contamination Fuel pump or circuit fault (relay) Intake system air leak Ballast resistor open circuit (older cars)
Erratic idle	Air filter blocked Incorrect plug gaps Inlet system air leak Incorrect CO setting Uneven or low cylinder compressions (maybe valves) Fuel injector fault Incorrect ignition timing Incorrect valve timing
Misfire at idle speed	Ignition coil or distributor cap tracking Poor cylinder compressions Engine breather blocked Inlet system air leak Faulty plugs
Misfire through all speeds	Fuel filter blocked Fuel pump delivery low Fuel tank ventilation system blocked Poor cylinder compressions Incorrect plugs or plug gaps HT leads breaking down
Engine stalls	Idle speed incorrect CO setting incorrect Fuel filter blocked Air filter blocked Intake air leak Idle control system not working
Lack of power	Fuel filter blocked Air filter blocked Ignition timing incorrect Low fuel pump delivery Uneven or low cylinder compressions (maybe valves) Fuel injectors blocked Brakes binding or clutch slipping
Backfires	Incorrect ignition timing Incorrect valve timing (cam belt not fitted correctly) Fuel system fault (airflow sensor on some cars)

(*Continued*)

Symptom	Possible cause
Oil pressure gauge low or warning light on	Low engine oil level Faulty sensor or switch Worn engine oil pump and/or engine bearings Engine overheating Oil pick-up filter blocked Pressure relief valve not working
Runs on when switched off	Ignition timing incorrect Idle speed too high Anti-run on device not working Carbon build-up in engine Engine overheating
Pinking or knocking under load	Ignition timing incorrect Ignition system fault Carbon build-up in engine Knock sensor not working
Sucking or whistling noises	Leaking exhaust manifold gasket Leaking inlet manifold gasket Cylinder head gasket Inlet air leak Water pump or alternator bearing
Rattling or tapping	Incorrect valve clearances Worn valve gear or camshaft Loose component
Thumping or knocking noises	Worn main bearings (deep knocking/rumbling noise) Worn big-end bearings (heavy knocking noise under load) Piston slap (worse when cold) Loose component
Rumbling noises	Bearings on ancillary component

6.4 Fuel system

Author's Note: Even though carburettor fuel systems are now very rare, they are still used on some specialist vehicles. For this reason, and because it serves as a good introduction to fuel systems, I decided to include this section.

6.4.1 Introduction

Key fact

A fuel system should produce the mixture at just the right ratio to run the engine under all operating conditions.

All vehicle fuel systems consist of the carburettor or fuel injectors, the fuel tank, the fuel pump and the fuel filter, together with connecting pipes. An engine works by the massive expansion of an ignited fuel air mixture acting on a piston. The job of the fuel system is to produce this mixture at just the right ratio to run the engine under all operating conditions. There are three main ways in which this is achieved:

- Petrol is mixed with air in a carburettor.
- Petrol is injected into the manifold, throttle body or cylinder to mix with the air.
- Diesel is injected under very high pressure directly into the air already in the engine combustion chamber.

This section examines only the carburettor systems; diesel and injection come under engine management later.



Figure 6.7 Single-choke and twin-choke carburettors

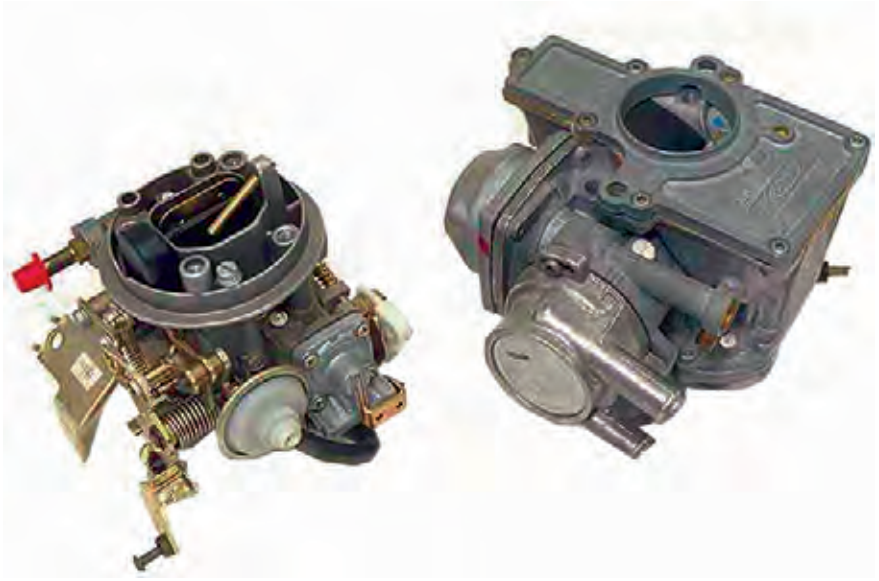


Figure 6.8 Fixed-choke and variable-choke carburettors

6.4.2 Carburation

The carburettor was the traditional method of mixing petrol with air as it enters the engine. However, a simple carburettor is only capable of providing a correct air and fuel mixture ratio within a very small engine speed range. For road vehicles, a wide engine speed range and a wide engine load is required. In order to respond to the speed and load variations, complex carburettors are used (Figure 6.7).

There are two basic carburettor designs: the f xed venturi and the variable venturi types. The term 'choke' is often used to describe the venturi and this gives the alternative carburettor def nitions of f xed choke and variable choke types. The usual meaning of the term 'choke' is to describe the engine cold start device f tted to the carburettor (Figure 6.8).

The function of the carburettor is to meter a quantity of petrol into the air stream entering the engine cylinders. As the pistons move down in the cylinders on the induction stroke, the pressure in the space above the cylinders falls. On naturally

Key fact

The function of the carburettor is to meter a quantity of petrol into the air stream entering the engine cylinders.

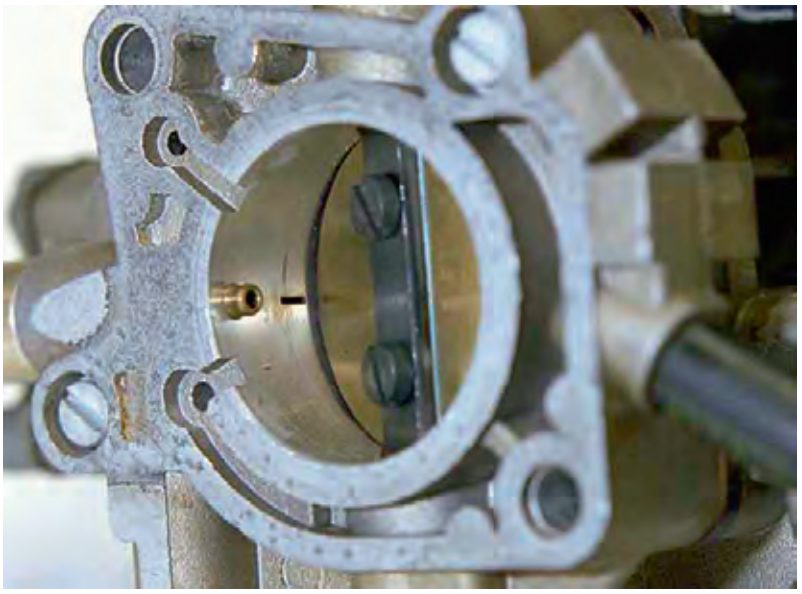


Figure 6.9 Throttle butterfly

aspirated engines, that is, those that are not fitted with pressure chargers, atmospheric pressure provides the force for the airflow into the cylinders.

The greater the difference in pressure, the greater will be the volume of air that enters the engine and the speed of the airflow through the carburettor and inlet manifold. A valve to meter the airflow is fitted at the base of the carburettor just in front of the inlet manifold. This valve is called the throttle and it consists of a round plate on a spindle. The spindle has a lever attached to one end and this is connected directly to the throttle pedal with a cable or rods. The throttle restricts the airflow in all positions except when wide open and this gives a range of variable pressures in the carburettor and the inlet manifold (Figure 6.9).

The basic carburettor consists of the venturi, through which the air flows, and the float chamber which holds a supply of petrol at a constant level in relation to the supply beak in the venturi. The level of petrol in the float chamber is maintained by a needle valve that is lifted onto its seat by the float so that it stops the flow when the chamber is full. As petrol is used the level drops, the needle valve opens and the flow of petrol into the chamber resumes. In this way, a constant petrol level is maintained. The float level should be checked and adjusted if necessary, if problems occur or if the carburettor is stripped for cleaning (Figure 6.10).

The main jet in the fuel feed to the venturi forms a restriction in the petrol flow and by virtue of its size acts as a metering device. The venturi is a tube with an inward curving restriction. Airflow through the venturi speeds up as it passes through the restriction. The effect of this is to reduce the air pressure at that point. Inside the float chamber, atmospheric pressure is applied to the top of the petrol held there. A vent in the top of the float chamber allows a free passage of air and atmospheric pressure (Figure 6.11).

A pressure differential exists at each end of the fuel supply tube between the float chamber and the venturi supply beak, when there is sufficient airflow to create a vacuum in the venturi. It is this pressure differential that is used to lift petrol up to the beak. From here, it passes into the air stream through the venturi and into the engine cylinders.

Although there is an increase in fuel delivery with an increase in airflow, these do not match sufficiently to maintain the correct air and fuel ratio over the full

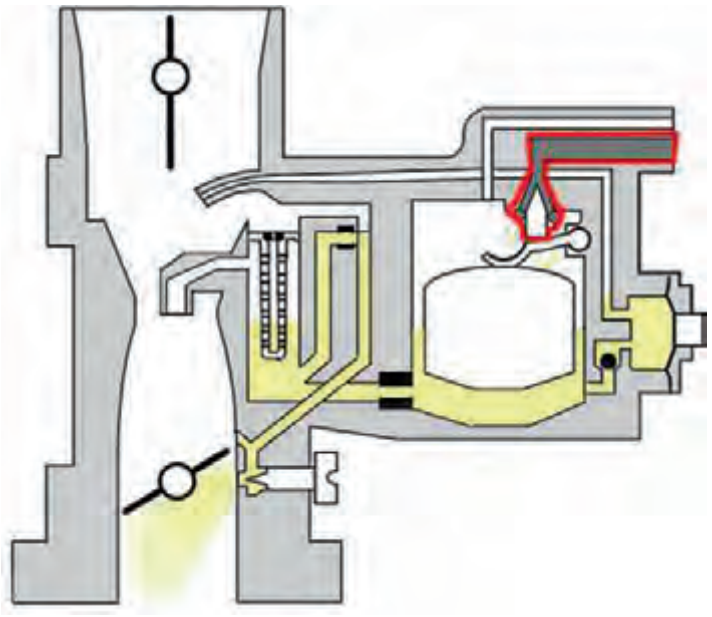


Figure 6.10 Fuel level is controlled by a float and needle valve

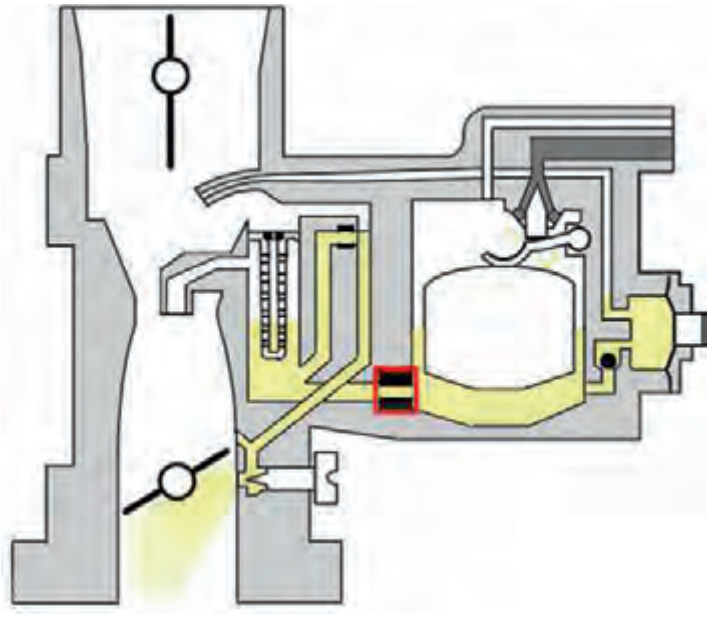


Figure 6.11 Main jet in the fuel feed to the venturi

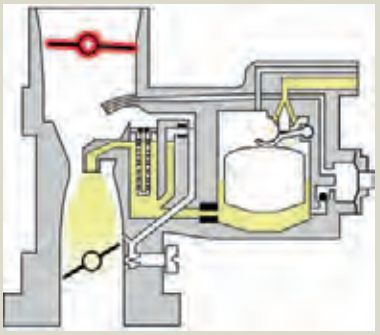
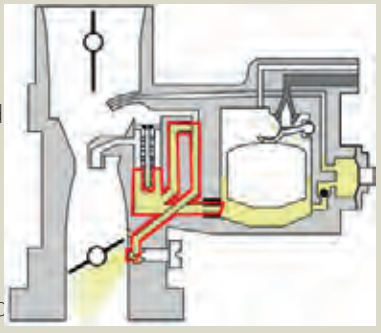
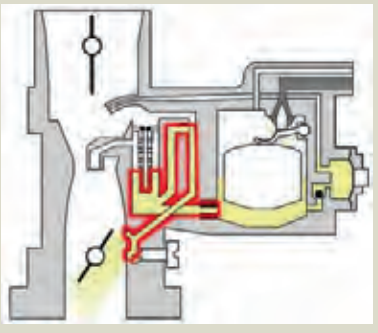
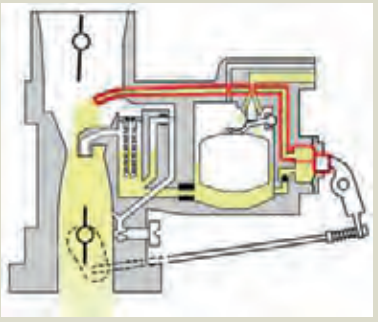
operating range. Other devices are needed to adjust the metering of petrol to the correct ratios. These are explained later in this section. The venturi can be positioned vertically with the airflow being downward or upward or it can be positioned horizontally. This gives the expressions downdraft, updraft and sidedraft for descriptions of carburettors.

There are six clearly identifiable engine and vehicle use conditions, known as the stages of carburation. These are outlined in Table 6.2.

Key fact

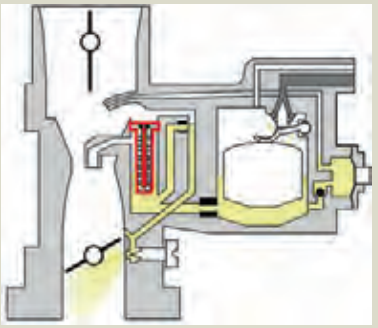
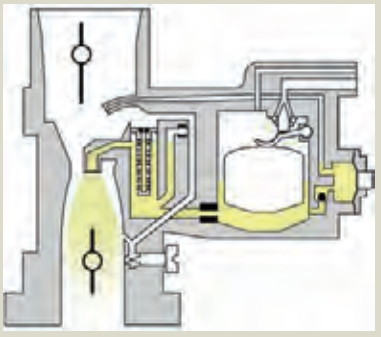
There are six clearly identifiable engine and vehicle use conditions, known as the stages of carburation.

Table 6.2 Stages of carburetion

Stage	Description	Diagram
Cold starting	Cold-start and warm-up conditions require a rich mixture. This is to keep the engine running smoothly and allow a smooth acceleration response. The mixture ratio for starting a vecold engine can be as low as 4:1. This ratio increases as the eng ne temperature increases, so that by the time the engine is at n rmal operating temperature, a correct ratio can be used. Cold-start enrichment devices on xed venturi carburettors use a choke plate at the top of the venturi. This lifts engine vacuum higher into the carburettor A manual choke plate is a pfitted to an offset spindle, which is rotated to the 'on' position by a spring when the choke is applied. The choke is held in the partial, a nd 'off' positions, by a cam connected to the choke cable. There is usually a linkage between the choke plate lever and the throtte, to increase the engine speed. This increase in speed is calle fast idle	 **Figure 6.12** Choke operation
Idle	On this carburettor the devices for engine idle or tick over can be seen. The air ow through the venturi restriction is insuffint at idle speeds to give the pressure differential requirement for petrol f ow into the venturi at the supply beak. The idle device is required to supply the low quantity of fuel needed at engine idle speeds. The vacuum in the inlet manifold is high when the throttle plate is closed. This vacuum is used in the idle device to create a flow of petrol and air through jets and drillings in the carburettor body The petrol and air mixture enters the air intake through the idle port just below the throttle plate. The size of the pilot petrol jet and adjustment of the air ow provides a suitable air to fuel ratio for engine idle operation	 **Figure 6.13** Idle circuit
Progression	Progression is used to describe the increase in engine speed from idle, up to the point where the venturi and main jet come into operation. At idle speeds, the air ow through the venturi is not enough to provide a suitable pressure differential. Normal venturi mixing of petrol in the air stream owing into the engine is therefore, not possible. Additional drillings in the lower part of the venturi, just above the throttle plate, connect to the float chamber This allows an extra fuel supply during this phase. There are some variations in the number and routing of these drillings, but they all provide for a smooth response to initial acceleration from idle	 **Figure 6.14** Progression air and fuel paths
Acceleration	If rapid acceleration is demanded, the vacuum in the venturi is lost for an instant when the throttle is opened quickly The petrol f ow through the supply beak from the float chamber cuts off and without a supplementary supply; a 'flat spot' would be experienced. To prevent flat spots on acceleration, an accelerator pump and petrol discharge nozzle are fitted. The pump consists of a piston or diaphragm, a one-way valve, and drillings for a petrol supply from the float chamber The pump is connected by a rod or cam linkage to the throttle plate lever. This causes a pulse of petrol to be sprayed into the venturi when rapid opening of the throttle is made	 **Figure 6.15** Accelerator pump and jet

(*Continued*)

Table 6.2 (Continued)

Stage	Description	Diagram
Cruising	The cruising speed range is wide and covers most operating conditions from light cruising up to a position just below full throttle. Petrol is drawn from the float chamber into the air stream passing into the engine. The supply beak design and position gives good atomization and distribution of the fuel in the air. The air fuel ratio in a simple venturi becomes richer with an increase in engine speed. In order to maintain the correct ratio mixture correction devices are used. It is also desirable for the engine to run on a lean mixture when the vehicle is cruising	 **Figure 6.16** Emulsion tube in use at cruise
Full load	Carburettors were designed to meet full throttle conditions without additional devices being fitted. However, these designs were unable to meet tougher environmental regulations, which required accurate control of exhaust emissions	 **Figure 6.17** Emulsion tube and 'beak' at full load

The development of twin-choke progressive carburettors was a way by which designers tackled the problems of maintaining correct mixture strengths, over the full range of engine operating conditions. The primary venturi works at the low throttle positions and a secondary venturi is added at the higher throttle positions. Electronic control using a temperature sensor and then a stepper motor to operate the choke has also been used. However, carburettors have had their chance, so fuel injection it is from now on!

6.5 Diagnostics – fuel system

6.5.1 Systematic testing example

If the reported fault is excessive fuel consumption, proceed as follows:

1. Check that the consumption is excessive for the particular vehicle. Test it yourself if necessary.
2. Are there any other problems with the vehicle, misfiring, for example, or difficult starting?
3. For example, if the vehicle is misfiring as well, this may indicate that an ignition fault is the cause of the problem.
4. Remove and examine spark plugs, check HT lead resistance and ignition timing. Check CO emissions.
5. Renew plugs and set fuel mixture.
6. Road-test the vehicle for correct engine operation.

Safety f rst

Note: You should always refer to the manufacturer's instructions appropriate to the equipment you are using.

6.5.2 Test equipment

Exhaust gas analyser

This is a sophisticated piece of test equipment used to measure the component gases of the vehicle's exhaust. The most common requirement is the measuring of carbon monoxide (CO). A sample probe is placed in the exhaust tail pipe or a special position before the catalytic converter (if f tted), and the machine reads out the percentage of certain gases produced. A digital readout is most common. The fuel mixture can then be adjusted until the required readings are obtained.

Fuel pressure gauge

The output pressure of the fuel pump can be tested to ensure adequate delivery. The device is a simple pressure gauge but note the added precautions necessary when dealing with petrol (Figure 6.18).

6.5.3 Test results

Some of the information you may have to get from other sources such as data books or a workshop manual is listed in Table 6.3.



Figure 6.18 Exhaust gas analyser

Table 6.3 Tests and information required

Test carried out	Information required
Exhaust gas analysis	CO setting. Most modern vehicles will have settings of approximately 1% or less. If a 'cat' is f then the readings will be even lower when measured at the tail pipe
Fuel pressure	The expected pressure readings will vary depending on the type of fuel system. Fuel injection pressure will be approximately 2.5 bar, whereas fuel pressure for a carburettor will be approximately 0.3 bar
Fuel delivery	How much fuel the pump should move in a set time will again vary with the type of fuel system. One litre in 30 seconds is typical for some injection fuel pumps

6.5.4 Fuel fault diagnosis table 1

Symptom	Possible faults	Suggested action
No fuel at carburettor or injection fuel rail	Empty tank! Blocked filter or line Defective fuel pump No electrical supply to pump	Fill it! Replace filter, renew/repair line Renew/check it is being driven Check fuses/trace fault
Engine will not or is difficult to start	Choke or enrichment device not working	Check linkages or automatic actuator
Engine stalls or will not idle smoothly	Idle speed incorrectly set Mixture setting wrong Ignition problem	Look up correct settings and adjust Look up correct settings and adjust Check ignition system
Poor acceleration	Blockage in carburettor accelerator pump Partially blocked filter Injection electrical fault	Strip down and clean out or try a carburettor cleaner first Renew Refer to specialist information
Excessive fuel consumption	Incorrect mixture settings Driving technique!	Look up correct settings and adjust Explain to the customer – but be diplomatic!
Black smoke from exhaust	Excessively rich mixture Flooding	Look up correct settings and adjust Check and adjust carburettor or fuel settings and operation

6.5.5 Fuel fault diagnosis table 2

Symptom	Possible cause
Excessive consumption	Blocked air filter Incorrect CO adjustment Fuel injectors leaking Ignition timing incorrect Temperature sensor fault Load sensor fault Low tyre pressures Driving style!
Fuel leakage	Damaged pipes or unions Fuel tank damaged Tank breathers blocked
Fuel smell	Fuel leak Breather incorrectly fitted Fuel cap loose Engine fooding
Incorrect emissions	Incorrect adjustments Fuel system fault Air leak into inlet Blocked fuel filter Blocked air filter Ignition system fault

6.6 Introduction to engine management

Key fact

Engine management is a general term that describes the control of engine operation.

Engine management is a general term that describes the control or manage the fuel, with an ignition distributor with contact breakers to control the ignition to a very sophisticated electronic control system. The fundamental tasks of an engine management system are to manage the ignition and fuelling, as well as other aspects, and to ref ne the basic control of an engine.

Many of the procedures and explanations in this chapter are generic. In other words, the ignition system explained in the following sections may be the same as the system used by a combined ignition and fuel control system.

6.7 Ignition

6.7.1 Basics

The purpose of the ignition system is to supply a spark inside the cylinder, near the end of the compression stroke, to ignite the compressed charge of air fuel vapour. For a spark to jump across an airgap of 0.6 mm under normal atmospheric conditions (1 bar), a voltage of 2–3 kV is required. For a spark to jump across a similar gap in an engine cylinder having a compression ratio of 8:1, a voltage of approximately 8 kV is required. For higher compression ratios and weaker mixtures, a voltage up to 20 kV may be necessary. The ignition system has to transform the normal battery voltage of 12 V to approximately 8–20 kV and, in addition, has to deliver this high voltage to the right cylinder, at the right time. Some ignition systems will supply up to 40 kV to the spark plugs.

Key fact

The fundamental operation of most ignition systems is very similar; one winding of a coil is switched on and off causing a high voltage to be induced in a second winding.

Conventional ignition is the forerunner of the more advanced systems controlled by electronics. However, the fundamental operation of most ignition systems is very similar; one winding of a coil is switched on and off causing a high voltage to be induced in a second winding. A coil ignition system is composed of various components and subassemblies; the actual design and construction of these depend mainly on the engine with which the system is to be used.

6.7.2 Advance angle (timing)

For optimum eff ciency, the ignition advance angle should be such as to cause the maximum combustion pressure to occur approximately 10° after TDC. The ideal ignition timing is dependent on two main factors: engine speed and engine load. An increase in engine speed requires the ignition timing to be advanced. The cylinder charge, of air fuel mixture, requires a certain time to burn (normally approximately 2 ms). At higher engine speeds, the time taken for the piston to travel the same distance reduces. Advancing the time of the spark ensures that full burning is achieved.

A change in timing due to engine load is also required, as the weaker mixture used in low-load conditions burns at a slower rate. In this situation, further ignition advance is necessary. Greater load on the engine requires a richer mixture, which burns more rapidly. In this case, some retardation of timing is necessary. Overall, under any condition of engine speed and load, an ideal advance angle is required to ensure maximum pressure is achieved in the cylinder just after TDC. The ideal advance angle may also be determined by engine temperature and any risk of detonation.

Spark advance is achieved in a number of ways. The simplest of these is the mechanical system comprising a centrifugal advance mechanism and a vacuum (load sensitive) control unit. Manifold depression is almost inversely proportional to the engine load. I prefer to consider manifold pressure, albeit less than atmospheric pressure; the absolute manifold pressure (MAP) is proportional to engine load. Digital ignition systems may adjust the timing in relation to the temperature as well as speed and load. The values of all ignition timing functions are combined either mechanically or electronically in order to determine the ideal ignition point.

The energy storage takes place in the ignition coil. The energy is stored in the form of a magnetic f eld. To ensure that the coil is charged before the ignition point, a dwell period is required. Ignition timing is at the end of the dwell period.

6.7.3 Electronic ignition

Electronic ignition is now f tted to all spark ignition vehicles. This is because the conventional mechanical system has some major disadvantages:

- Mechanical problems with the contact breakers not least of which is the limited lifetime.
- Current f ow in the primary circuit is limited to approximately 4 A, otherwise damage will occur to the contacts – or at least the lifetime will be seriously reduced.
- Legislation requires stringent emission limits which means the ignition timing must stay in tune for a long period of time.
- Weaker mixtures require more energy from the spark to ensure successful ignition, even at very high engine speed.

These problems can be overcome by using a power transistor to carry out the switching function and a pulse generator to provide the timing signal. Very early forms of electronic ignition used the existing contact breakers as the signal provider. This was a step in the right direction but did not overcome all the mechanical limitations such as contact bounce and timing slip. All systems nowadays are constant-energy systems ensuring high-performance ignition even at high engine speed. Figure 6.19 shows the circuit of a standard electronic ignition system.

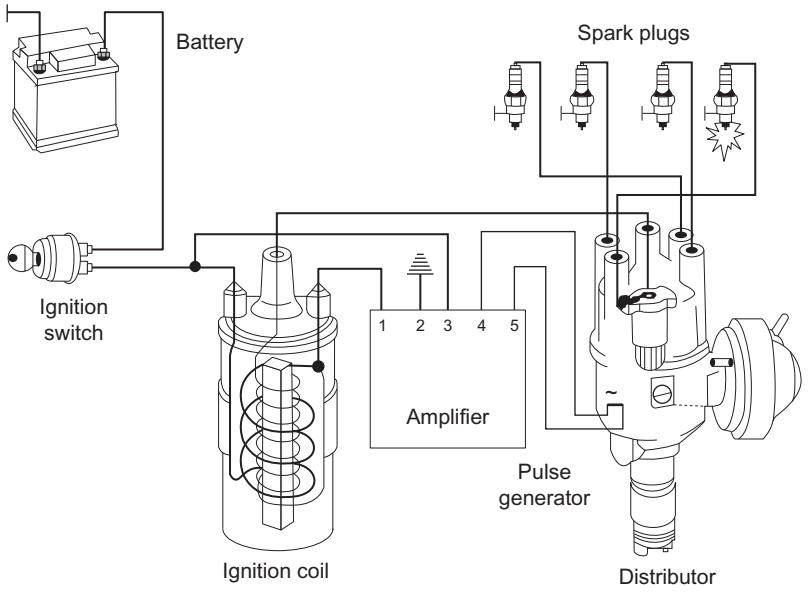


Figure 6.19 Early electronic ignition system

Key fact

The term 'dwell' when applied to ignition is a measure of the time during which the ignition coil is charging – in other words, when primary current is flowing.

The term 'dwell' when applied to ignition is a measure of the time during which the ignition coil is charging – in other words, when primary current is flowing. The dwell in conventional systems was simply the time during which the contact breakers were closed. This is now often expressed as a percentage of one charge–discharge cycle. Constant-dwell electronic ignition systems have now been replaced almost without exception by constant-energy systems discussed in the next section.

Although this was a very good system in its time, constant dwell still meant that at very high engine speeds, the time available to charge the coil could only produce a lower-power spark. Note that as engine speed increases, dwell angle or dwell percentage remains the same but the actual time is reduced.

Key fact

In order for a constant-energy electronic ignition system to operate, the dwell must increase with engine speed.

In order for a constant-energy electronic ignition system to operate, the dwell must increase with engine speed. This will only be of benefit, however, if the ignition coil can be charged up to its full capacity, in a very short time (the time available for maximum dwell at the highest expected engine speed). To this end, constant-energy coils are very low resistance and low inductance. Typical resistance values are less than 1 Ω (often 0.5 Ω). Constant energy means that, within limits, the energy available to the spark plug remains constant under all operating conditions.

Owing to the high-energy nature of constant-energy ignition coils, the coil cannot be allowed to remain switched on for more than a certain time. This is not a problem when the engine is running, as the variable-dwell or current-limiting circuit prevents the coil from overheating. Some form of protection must be provided, however, for when the ignition is switched on but the engine is not running. This is known as stationary engine primary current cut-off.

6.7.4 Hall effect distributor

The Hall effect distributor has become very popular with many manufacturers. Figure 6.20 shows a typical example. As the central shaft of the distributor rotates, the chopper plate attached under the rotor arm alternately covers and uncovers the Hall chip. The number of vanes corresponds with the number of cylinders. In constant-dwell systems, the dwell is determined by the width of the vanes. The vanes cause the Hall chip to be alternately in and out of a magnetic



Figure 6.20 Hall effect distributor

f eld. The result of this is that the device will produce almost a square wave output, which can then easily be used to switch further electronic circuits.

The three terminals on the distributor are marked '−', '0' and '+'; the terminals '−' and '+' are for a voltage supply and terminal '0' is the output signal. Typically, the output from a Hall effect sensor will switch between 0 V and approximately 8 V. The supply voltage is taken from the ignition ECU and on some systems is stabilised at approximately 10 V to prevent changes to the output of the sensor when the engine is being cranked.

Hall effect distributors were very common due to the accurate signal produced and long-term reliability. They are suitable for use on both constant-dwell and constant-energy systems. Operation of a Hall effect pulse generator can easily be tested with a DC voltmeter or a logic probe. Note that tests must not be carried out using an ohmmeter, as the voltage from the meter can damage the Hall chip.

6.7.5 Inductive distributor

Many forms of inductive-type distributors exist and all are based around a coil of wire and a permanent magnet. The example distributor shown in Figure 6.21 has the coil of wire wound on the pick-up, and as the reluctor rotates, the magnetic f ux varies due to the peaks on the reluctor. The number of peaks or teeth on the reluctor corresponds to the number of engine cylinders. The gap between the reluctor and pick-up can be important and manufacturers have recommended settings.

Key fact

Many forms of inductive-type distributors exist and all are based around a coil of wire and a permanent magnet.

6.7.6 Current-limiting and closed-loop dwell

Primary current limiting not only ensures that no damage can be caused to the system by excessive primary current but also forms a part of a constant-energy system. The primary current is allowed to build up to its pre-set maximum as soon as possible and is then held at this value. The value of this current is calculated and then pre-set during construction of the amplif er module. This technique, when combined with dwell angle control, is known as closed-loop control as the actual value of the primary current is fed back to the control stages.



Figure 6.21 Inductive distributor

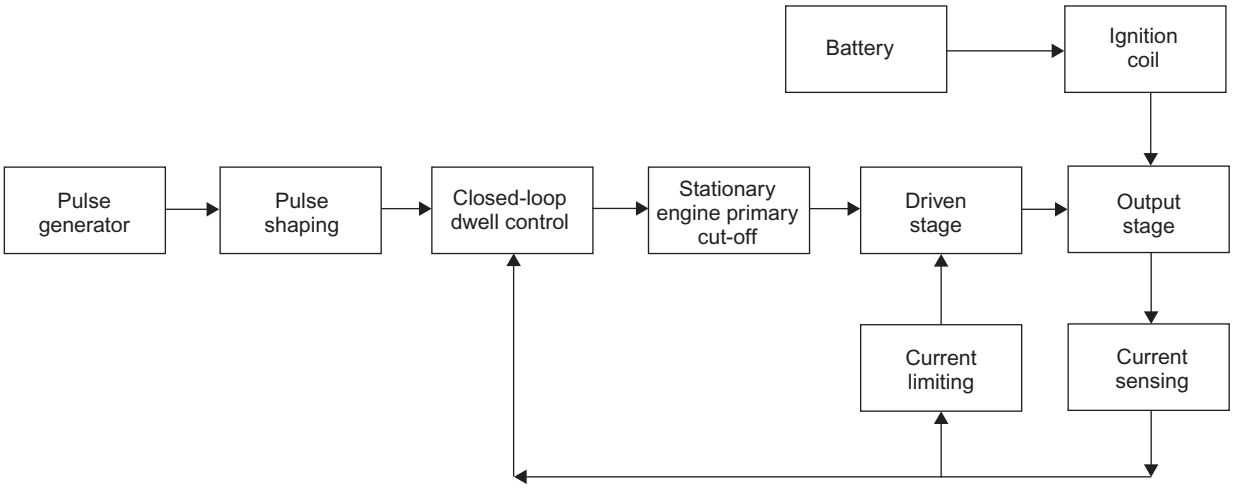


Figure 6.22 Closed-loop dwell control system

A very low resistance, high power precision resistor is used in this circuit. The resistor is connected in series with the power transistor and the ignition coil. A voltage-sensing circuit connected across this resistor is activated at a pre-set voltage (which is proportional to the current) and causes the output stage to hold the current at a constant value.

Stationary current cut-off is for when the ignition is on but the engine is not running. This is achieved in many cases by a simple timer circuit, which will cut the output stage after about one second (Figure 6.22).

6.7.7 Programmed ignition/electronic spark advance

Definition

ESA: Electronic spark advance.

Programmed ignition is the term used by some manufacturers; others call it electronic spark advance (ESA). Constant-energy electronic ignition was a major step forwards and is still used on countless applications. However, its limitations lay in still having to rely upon mechanical components for speed and load advance characteristics. In many cases, these did not match ideally the requirements of the engine.

ESA systems have a major difference compared with earlier systems in that they operate digitally. Information about the operating requirements of a particular engine is programmed into memory inside the ECU. The data for storage in ROM is obtained from rigorous testing on an engine dynamometer and further development work in the vehicle under various operating conditions. Programmed ignition has several advantages:

- The ignition timing can be accurately matched to the individual application under a range of operating conditions.
- Other control input can be utilised such as coolant temperature and ambient air temperature.
- Starting is improved, fuel consumption and emissions are reduced, and idle control is better.
- Other inputs can be taken into account such as engine knock.
- The number of wearing components in the ignition system is considerably reduced.

Programmed ignition or ESA can be a separate system or included as part of the fuel control system. In order for the ECU to calculate suitable timing and dwell outputs, certain input information is required.

The crankshaft sensor consists of a permanent magnet, a winding and a soft iron core. It is mounted in proximity to a reluctor disc. The disc has 34 teeth spaced at 10° intervals around to periphery. It has two teeth missing 180° apart, at a known position BTDC. Many manufacturers use this technique with minor differences. As a tooth from the reluctor disc passes the core of the sensor, the reluctance of the magnetic circuit is changed. This induces a voltage in the winding, the frequency of the waveform being proportional to the engine speed. The missing tooth causes a 'missed' output wave and hence engine position can be determined.

Engine load is proportional to manifold pressure in that high-load conditions produce high pressure and lower-load conditions, such as cruise, produce lower pressure. Load sensors are therefore pressure transducers. They are either mounted in the ECU or as a separate unit and are connected to the inlet manifold with a pipe. The pipe often incorporates a restriction to damp out f uctuations and a vapour trap to prevent petrol fumes reaching the sensor.

Key fact

Engine load is proportional to manifold pressure in that high-load conditions produce high pressure and lowerload conditions, such as cruise, produce lower pressure.

Coolant temperature measurement is carried out by a simple thermistor. In many cases, the same sensor is used for the operation of the temperature gauge and to provide information to the fuel control system. A separate memory map is used to correct the basic timing settings. Timing may be retarded when the engine is cold to assist in more rapid warm-up.

Combustion knock can cause serious damage to an engine if sustained for long periods. This knock or detonation is caused by overadvanced ignition timing. At variance with this is that an engine in general will run at its most eff cient when the timing is advanced as far as possible. To achieve this, the data stored in the basic timing map will be as close to the knock limit of the engine as possible. The knock sensor provides a margin for error. The sensor itself is an accelerometer often of the piezoelectric type. It is f tted in the engine block between cylinders 2 and 3 on in-line four-cylinder engines. Vee engines require two sensors, one on each side. The ECU responds to signals from the knock sensor in the engine's knock window for each cylinder; this is often just a few degrees each side of TDC. This prevents clatter from the valve mechanism being interpreted as knock. The signal from the sensor is also f ltered in the ECU to remove unwanted noise. If detonation is detected, the ignition timing is retarded on the fourth ignition pulse after detection (four-cylinder engine), in steps until knock is no longer detected. The steps vary between manufacturers, but approximately 2° is typical. The timing is then advanced slowly in steps of say 1° over a number of engine revolutions, until the advance required by memory is restored. This f ne control allows the engine to be run very close to the knock limit without risk of engine damage.

Key fact

Combustion knock can cause serious damage to an engine if sustained for long periods.

Correction to dwell settings is required if the battery voltage falls, as a lower voltage supply to the coil will require a slightly larger dwell f gure. This information is often stored in the form of a dwell correction map.

As the sophistication of systems has increased, the information held in the memory chips of the ECU has also increased. The earlier versions of programmed ignition system produced by Rover achieved accuracy in ignition timing of ±1.8°, whereas a conventional distributor is ±8°. The information, which is derived from dynamometer tests as well as running tests in the vehicle, is stored in ROM. The basic timing map consists of the correct ignition advance for 16 engine speeds and 16 engine load conditions.

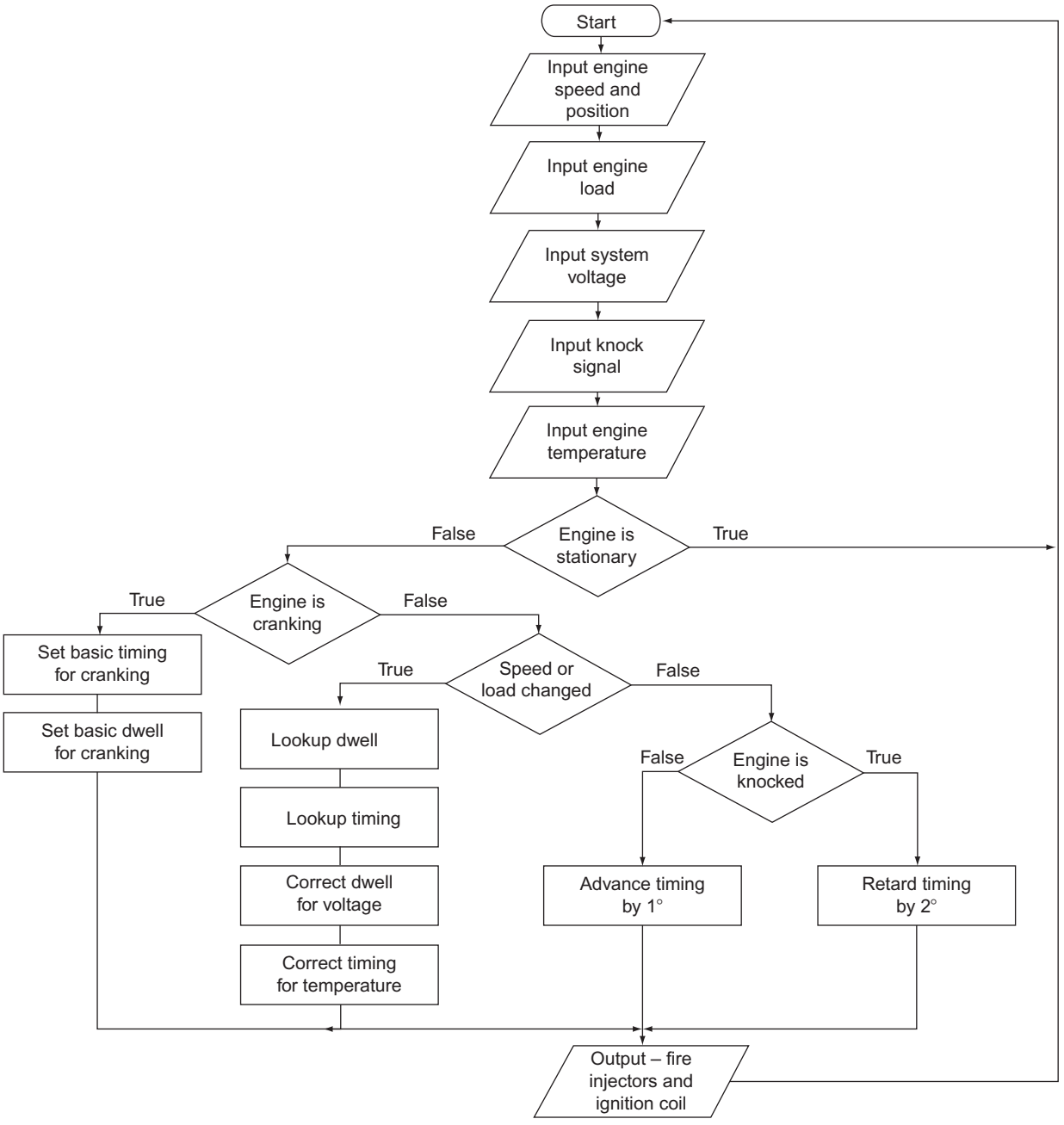


Figure 6.23 Electronic spark advance: representation of the process

A separate three-dimensional map is used which has eight speed and eight temperature sites. This is used to add corrections for engine coolant temperature to the basic timing settings. This improves driveability and can be used to decrease the warm-up time of the engine. The data is also subjected to an additional load correction below 70 °C. Figure 6.23 shows a f ow chart representing the logical selection of the optimum ignition setting. Note that the ECU will also make corrections to the dwell angle, both as a function of engine speed to provide constant energy output and due to changes in battery voltage. A lower battery voltage will require a slightly longer dwell and a higher battery voltage will require a slightly shorter dwell. A Windows® shareware program that simulates the ignition system (as well as many other systems) is available for download from my website.

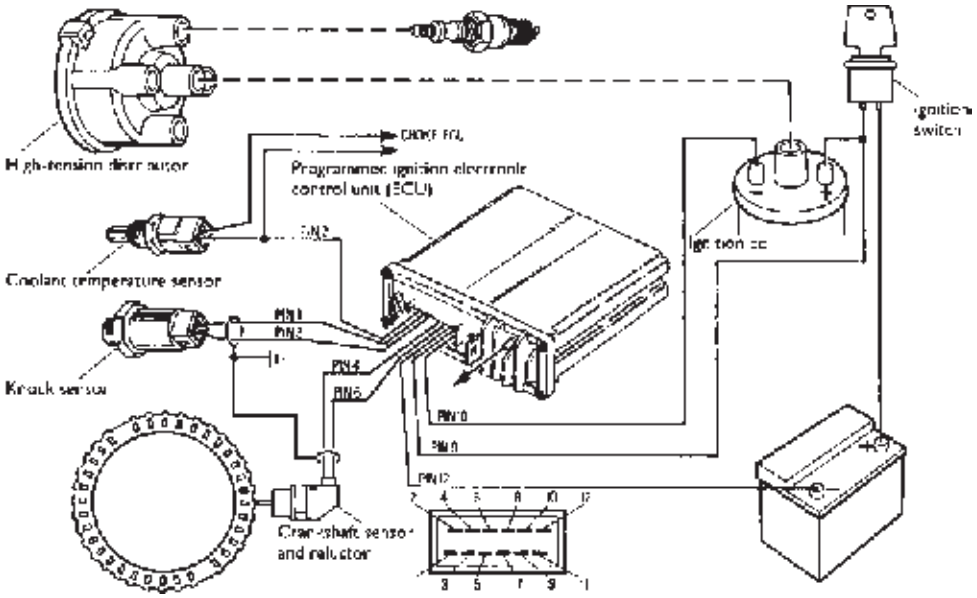


Figure 6.24 Programmed ignition system electronic spark advance (ESA)

The output of a system such as this programmed ignition is very simple. The output stage, in common with most electronic ignition, consists of a heavy-duty transistor which forms part of, or is driven by, a Darlington pair. This is simply to allow the high ignition primary current to be controlled. The switch-off point of the coil will control ignition timing and the switch-on point will control the dwell period.

The high-tension distribution is similar to a more conventional system. The rotor arm, however, is mounted on the end of the camshaft with the distributor cap positioned over the top. Figure 6.24 shows an early programmed ignition system.

6.7.8 Distributorless ignition

Distributorless ignition has all the features of ESA ignition systems but, by using a special type of ignition coil, outputs to the spark plugs without the need for an HT distributor. The system is generally only used on four-cylinder engines, as the control system becomes too complex for higher numbers. The basic principle is that of the 'lost spark'. The distribution of the spark is achieved by using double-ended coils, which are f red alternately by the ECU. The timing is determined from a crankshaft speed and position sensor as well as load and other corrections. When one of the coils is f red, a spark is delivered to two-engine cylinders, either 1 and 4, or 2 and 3. The spark delivered to the cylinder on the compression stroke will ignite the mixture as normal. The spark produced in the other cylinder will have no effect, as this cylinder will be just completing its exhaust stroke.

Because of the low compression and the exhaust gases in the 'lost spark' cylinder, the voltage used for the spark to jump the gap is only approximately 3 kV. This is similar to the more conventional rotor arm to cap voltage. The spark produced in the compression cylinder is therefore not affected.

An interesting point here is that the spark on one of the cylinders will jump from the earth electrode to the spark plug centre. Many years ago, this would not have been acceptable, as the spark quality when jumping this way would not have

Key fact

Because of the low compression and the exhaust gases in the 'lost spark' cylinder, the voltage used for the spark to jump the gap is only approximately 3kV.



Figure 6.25 DIS coil on a four-cylinder engine

been as good as when it jumps from the centre electrode. However, the energy available from modern constant-energy systems will produce a spark of suitable quality in either direction.

The direct ignition system (DIS) consists of three main components: the electronic module, a crankshaft position sensor and the DIS coil. In many systems, a MAP sensor is integrated in the module. The module functions in much the same way as has been described for the ESA system.

The crankshaft position sensor is similar in operation to the one described in the previous section. It is again a reluctance sensor and is positioned against the front of the flywheel or against a reluctor wheel just behind the front crankshaft pulley. The tooth pattern consists of 35 teeth. These are spaced at 10° intervals with a gap where the 36th tooth would be. The missing tooth is positioned at 90° BTDC for numbers 1 and 4 cylinders. This reference position is placed a fixed number of degrees before TDC, in order to allow the timing or ignition point to be calculated as a fixed angle after the reference mark (Figure 6.25).

The low-tension winding is supplied with battery voltage to a centre terminal. The appropriate half of the winding is then switched to earth in the module. The high-tension windings are separate and are specific to cylinders 1 and 4, or 2 and 3.

6.7.9 Direct ignition

Direct ignition is in a way the follow-on from distributorless ignition. This system utilises an inductive coil for each cylinder. These coils are mounted directly on the spark plugs. Figure 6.26 shows a cross-section of the direct ignition coil. The use of an individual coil for each plug ensures that the rise time for the low-inductance primary winding is very fast. This ensures that a very high voltage, high-energy spark is produced. This voltage, which can be in excess of 400 kV, provides efficient initiation of the combustion process under cold starting conditions and with weak mixtures. Some direct ignition systems use capacitor discharge ignition.

Key fact

The use of an individual coil for each plug ensures that the rise time for the low-inductance primary winding is very fast.

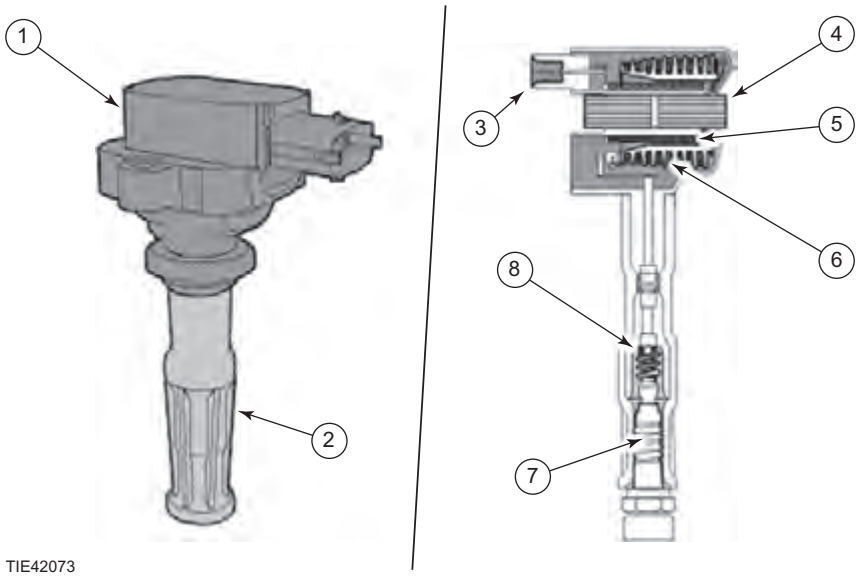


Figure 6.26 Direct ignition coil features: 1 – direct ignition coil; 2 – spark plug connector; 3 – low-voltage connection; outer: 4 – laminated iron core; 5 – primary winding; 6 – secondary winding; 7 – spark plug; 8 – high-voltage connection; inner: via spring contact. (Source: Ford Motor Company)

In order to switch the ignition coils, igniter units may be used. These can control up to three coils and are simply the power stages of the control unit but in a separate container. This allows less interference to be caused in the main ECU due to heavy current switching and shorter runs of wires carrying higher currents.

Ignition timing and dwell are controlled in a manner similar to the previously described programmed system. The one important addition to this on some systems is a camshaft sensor to provide information as to which cylinder is on the compression stroke. A system which does not require a sensor to determine which cylinder is on compression (engine position is known from a crank sensor) determines the information by initially f ring all the coils. The voltage across the plugs allows measurement of the current for each spark and will indicate which cylinder is on its combustion stroke. This works because a burning mixture has a lower resistance. The cylinder with the highest current at this point will be the cylinder on the combustion stroke.

A further feature of some systems is the case when the engine is cranked over for an excessive time making f ooding likely. The plugs are all f red with multisparks for a period of time after the ignition is left in the ‘on’ position for f ve seconds. This will burn away any excess fuel.

During diff cult starting conditions, multisparking is also used by some systems during 70° of crank rotation before TDC. This assists with starting and then once the engine is running, the timing will return to its normal calculated position.

6.7.10 Spark plugs

Figure 6.27 shows a standard spark plug. The centre electrode is connected to the top terminal by a stud. The electrode is constructed of a nickel-based alloy.

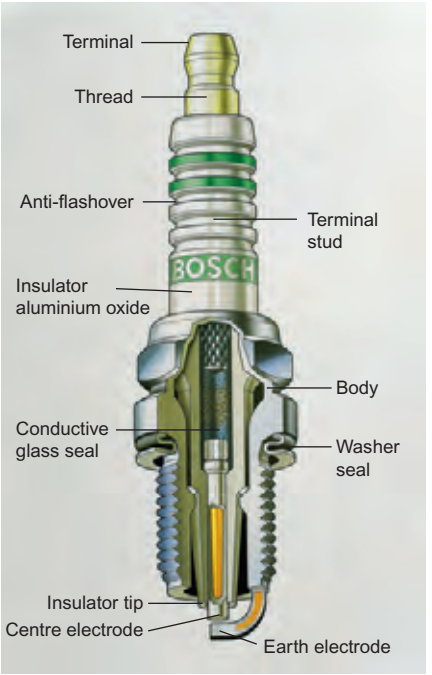


Figure 6.27 Construction of a copper cored spark plug

Silver and platinum are also used for some applications. If a copper core is used in the electrode, this improves the thermal conduction properties.

The insulating material is ceramic based and of a very high grade. The electrically conductive glass seal between the electrode and terminal stud is also used as a resistor. This resistor has two functions: f rst to prevent burn-off of the centre electrode, and second to reduce radio interference. In both cases, the desired effect is achieved because the resistor damps the current at the instant of ignition.

Flashover or tracking down the outside of the plug insulation is prevented by ribs. These effectively increase the surface distance from the terminal to the metal f xing bolt, which is of course earthed to the engine.

Owing to the many and varied constructional features involved in the design of an engine, the range of temperatures a spark plug is exposed to can vary signif cantly. The operating temperature of the centre electrode of a spark plug is critical. If the temperature becomes too high then pre-ignition may occur, as the fuel air mixture may become ignited due to the incandescence of the plug electrode. On the other hand, if the electrode temperature is too low then carbon and oil fouling can occur, as deposits are not burnt off. Fouling of the plug nose can cause shunts (a circuit in parallel with the spark gap). It has been shown through experimentation and experience that the ideal operating temperature of the plug electrode is between 400 and 900 °C.

Key fact

The heat range of a spark plug then is a measure of its ability to transfer heat away from the centre electrode.

The heat range of a spark plug then is a measure of its ability to transfer heat away from the centre electrode. A hot running engine will require plugs with a higher thermal loading ability than a colder running engine. Note that hot and cold running of an engine in this sense refers to the combustion temperature and not to the eff ciency of the cooling system.

The following factors determine the thermal capacity of a spark plug:

- insulator nose length;
- electrode material;
- thread contact length;
- projection of the electrode.

It has been found that a longer projection of the electrode helps to reduce fouling problems due to low-power operation, stop-go driving and high-altitude conditions. To use greater projection of the electrode, better-quality thermal conduction is required to allow suitable heat transfer at higher power outputs. Figure 6.28 shows the heat conducting paths of a spark plug together with changes in design for heat ranges.

For normal applications, alloys of nickel are used for the electrode material. Chromium, manganese, silicon and magnesium are examples of the alloying constituents. These alloys exhibit excellent properties with respect to corrosion and burn-off resistance. To improve on the thermal conductivity, compound electrodes are used. This allows a greater nose projection for the same temperature range as discussed in the last section. A common example of this type of plug is the copper core spark plug.

Silver electrodes are used for specialist applications, as silver has very good thermal and electrical properties. Again with these plugs nose length can be increased within the same temperature range. Platinum tips are used for some

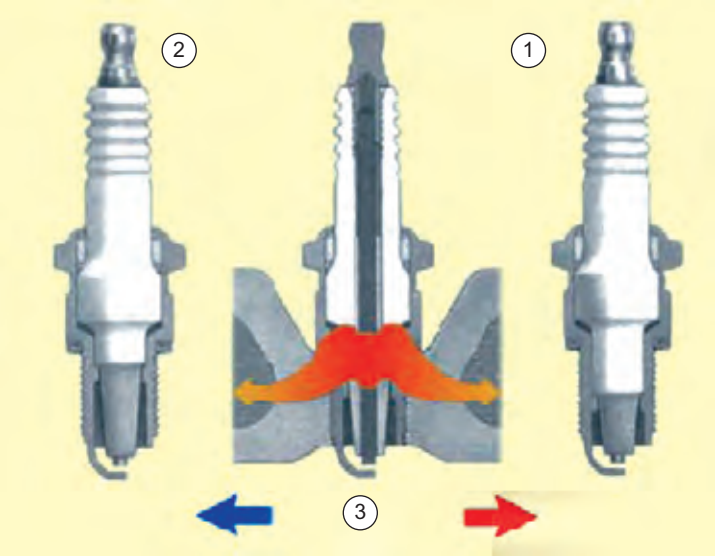


Figure 6.28 Heat-loss paths: 1 – cold plug; 2 – hot plug; 3 – temperature (the cold plug is able to transfer heat more easily so is suitable for a hot engine)

spark plug applications due to the very high burn-off resistance of this material. It is also possible because of this to use much-smaller-diameter electrodes, thus increasing mixture accessibility. Platinum also has a catalytic effect, further accelerating the combustion process.

Spark plug electrode gaps in general have increased as the power of the ignition systems driving the spark has increased. The simple relationship between plug gap and voltage required is that as the gap increases, so must the voltage (leaving aside engine operating conditions). Further, the energy available to form a spark at a f xed engine speed is constant, which means that a larger gap using higher voltage will result in a shorter-duration spark. A smaller gap will allow a longer-duration spark. For cold starting an engine and for igniting weak mixtures, the duration of the spark is critical. Likewise, the plug gap must be as large as possible to allow easy access for the mixture to prevent quenching of the f ame.

The f nal choice is therefore a compromise reached through testing and development of a particular application. Plug gaps in the region of 0.6–1.2 mm seem to be the norm at present.

Key fact

Spark plug electrode gaps in general have increased as the power of the ignition systems driving the spark has increased.

Safety f rst

Warning: Caution/Achtung/Attention – High voltages can seriously damage your health.

6.8 Diagnostics – ignition system

6.8.1 Testing procedure

The following procedure is generic and with a little adaptation can be applied to any ignition system. Refer to manufacturer's recommendations if in any doubt (Figure 6.29).

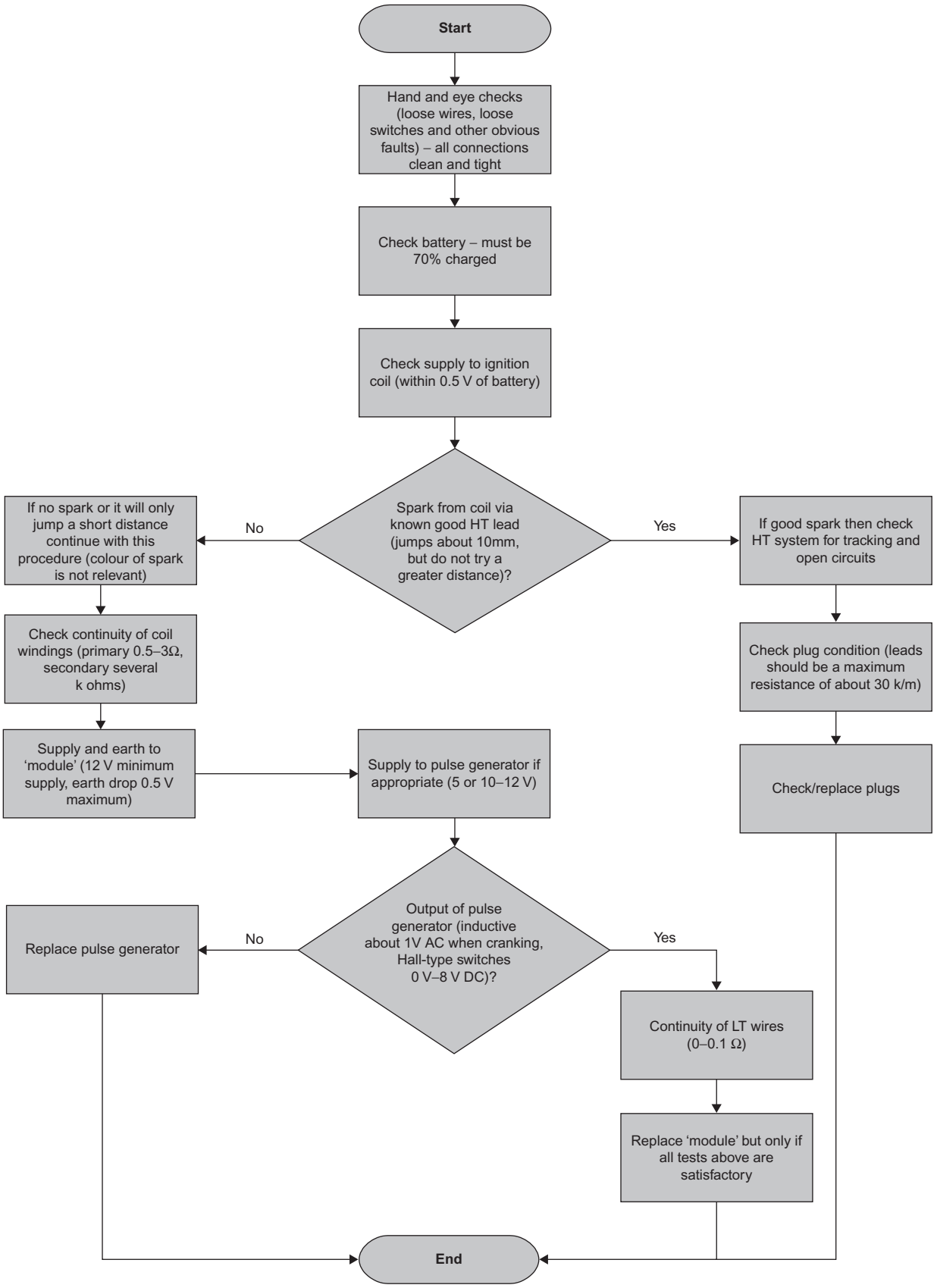


Figure 6.29 Ignition system diagnosis chart

6.8.2 Ignition fault diagnosis table

Symptom	Possible fault
Engine rotates but does no start	Damp ignition components Spark plugs worn to excess Ignition system open circuit
Diff cult to start when cold	Spark plugs worn to excess High resistance in ignition circuit
Engine starts but then stop immediately	Ignition wiring connection intermittent Ballast resistor open circuit (older cars)
Erratic idle	Incorrect plug gaps Incorrect ignition timing
Misf re at idle speed	Ignition coil or distributor cap tracking Spark plugs worn to excess Dwell incorrect (old systems)
Misf re through all speeds	Incorrect plugs or plug gaps HT leads breaking down Timing incorrect
Lack of power	Ignition timing incorrect HT components tracking
Backf res	Incorrect ignition timing Tracking
Runs on when switched of	Ignition timing incorrect Carbon build-up in engine Idle speed too high Anti-run on device inoperative
Pinking or knocking under load	Ignition timing incorrect Ignition system electronic fault Knock sensor not working

Figure 6.30 shows a typical ignition timing light, essential to ensure correct settings where these are adjustable, or to check programmed advance systems for correct operation.

6.8.3 Ignition components and testing

Component	Description	Test method
Spark plug	Seals electrodes for the spark to jump across the cylinder. Must withstand very high voltages, pressures and temperatures	Compare nose condition to a manufacturer chart Inspect ignition secondary waveform, particularly when the engine is under load
Ignition coil	Stores energy in the form of magnetism and delivers it to the distributor via the HT lead. Consists of primary and secondary windings	Resistance checks of the primary and secondary windings: Primary: 1.5Ω (ballasted) to Ω Secondary: 5–10kΩ

(*Continued*)

Component	Description	Test method
Ignition switch	Provides driver control of the ignition system and is usually also used to cause the starter to crank	Voltage drop across the contacts
Ballast resistor	Shorted out during the starting phase to cause a more powerful spark. Also contributes towards improving the spark at higher speeds	Resistance (often approximately 1.5Ω) or check voltage at coil supply (approximately 6 or 7 when the contact breakers are closed)
Contact breakers (breaker points)	Switch the primary ignition circuit on and off to charge and discharge the coil	Voltage drop across them should not exceed approximately 0.2V General condition
Capacitor (condenser)	Suppresses most of the arcing as the contact breakers open. This allows for a more rapid break of primary current and hence a more rapid collapse of the coil magnetism, which produces a higher voltage output	Charge the capacitor up across a 12V battery. Connect a digital meter and watch the voltage discharge from 12V to almost 0V over approximately five seconds
HT distributor	Directs the spark from the coil to each cylinder in a pre-set sequence	Visual inspection for signs of tracking (conducting lines) and contamination
Centrifugal advance (engine speed)	Changes the ignition timing with engine speed. As speed increases, the timing is advanced	Measure the timing at certain speeds using an 'advance' timing light. Refer to data
Vacuum advance (engine load)	Changes timing depending on engine load. On conventional systems, the vacuum advance is most important during cruise conditions	Apply a known vacuum and note timing changes or often just sucking on the pipe and noting movement is adequate



Figure 6.30 Timing light (used on earlier cars)

6.8.4 DIS diagnostics

The DIS system is very reliable due to the lack of any moving parts. Some problems can be experienced when trying to examine HT oscilloscope patterns due to the lack of a king lead. This can often be overcome with a special adapter, but it is still necessary to move the sensing clip to each lead in turn.

The DIS coil can be tested with an ohmmeter. The resistance of each primary winding should be 0.5 Ω and the secondary windings between 11 and 16 kΩ. The coil will produce in excess of 37 kV in an open circuit condition. The plug leads have integral retaining clips to prevent water ingress and vibration problems. The maximum resistance for the HT leads is 30 kΩ per lead.

No service adjustments are possible with this system, with the exception of octane adjustment on some models. This involves connecting two pins together on the module for normal operation, or earthing one pin or the other to change to a different fuel. The actual procedure must be checked with the manufacturer for each particular model.

6.8.5 Spark plugs

Examination of the spark plugs is a good way of assessing engine and associated systems condition. Figure 6.31 shows a new plug and Figures 6.32–6.36 show various conditions with diagnostic notes added.

Key fact

Examination of the spark plugs is a good way of assessing engine and associated systems condition.



Figure 6.31 New spark plug

Use this image to compare with used spark plugs. Note in particular on this standard design, how the end of the nose is tapered and that the earth/ground electrode has a consistent size and shape



Figure 6.32 Carbon fouled (standard plug)

This plug has black deposits over the centre electrode and insulator in particular It is likely that this engine was running too rich – or on an older vehicle the choke was used excessively However, carbon fouling may also be due to
poor-quality spark due to ignition fault
incorrect plug gap
overretarded timing
loss of cylinder compression
prolonged low-speed driving
incorrect (too cold) spark plug fitted

(*Continued*)



Figure 6.33 Deposits

The deposits on this plug are most likely to be caused by oil leaking into the cylinder. Alternatively, poor-quality fuel mixture supply or very short, cold engine operation could result in a similar condition.



Figure 6.34 Damaged insulation

A plug that is damaged in this way is because of either overheating or impact damage. Impact is most likely in this case. The damage can of course be caused as the plug is being fitted. However, in this case a possible cause would be that the reach was too long for the engine and the piston hit the earth/ground electrode, closing up the gap and breaking the insulation.



Figure 6.35 Carbon fouled (platinum plug)

The carbon build-up on this plug would suggest an incorrect mixture. However, before diagnosing a fault based on spark plug condition, make sure the engine has been run up to temperature – ideally by a good road test. The engine from which this plug was removed is in good condition – it had just been started from cold and only run for a few minutes.



Figure 6.36 Overheating

When a plug overheats, the insulator tip becomes glossy and/or they are blistered or melted away. The electrodes also wear quickly. Excessive overheating can result in the electrodes melting and serious piston damage is likely to occur. Causes of overheating are:

- overadvanced ignition
- mixture too lean
- cooling system fault
- incorrect plug (too hot)
- incorrect fuel (octane low)

6.9 Emissions

6.9.1 Introduction

Table 6.4 lists the four main exhaust emissions which are hazardous to health together with a short description of each.

Table 6.5 describes two further sources of emissions from a vehicle.

Table 6.4 Exhaust emissions

Substance	Description
Carbon monoxide (CO)	This gas is very dangerous even in low concentrations. It has no smell or taste and is colourless. When inhaled, it combines in the body with the red blood cells preventing them from carrying oxygen. If absorbed by the body it can be fatal in a very short time
Nitrogen oxides (NO_x)	Oxides of nitrogen are colourless and odourless when they leave the engine, but as soon as they reach the atmosphere and mix with more oxygen, nitrogen oxides are formed. They are reddish brown and have an acrid and pungent smell. These gases damage the body's respiratory system when inhaled. When combined with water vapour nitric acid can be formed, which is very damaging to the windpipe and lungs. Nitrogen oxides are also a contributing factor to acid rain
Hydrocarbons (HC)	A number of different hydrocarbons are emitted from an engine and are part of unburnt fuel. When they mix with the atmosphere, they can help to form smog. It is also believed that hydrocarbons may be carcinogenic
Particulate matter (PM)	This heading in the main covers lead and carbon. Lead was traditionally added to petrol to slow its burning rate to reduce detonation. It is detrimental to health and is thought to cause brain damage, especially in children. Lead will eventually be phased out as all new engines now run on unleaded fuel. Particles of soot or carbon are more of a problem on diesel-fuelled vehicles and these now have limits set by legislation

Table 6.5 Emission sources

Source	Comments
Fuel evaporation from the tank and system	Fuel evaporation causes hydrocarbons to be produced. The effect is greater as temperature increases. A charcoal canister is the preferred method for reducing this problem. The fuel tank is usually run at a pressure just under atmospheric by a connection to the intake manifold drawing the vapour through the charcoal canister. This must be controlled by the management system, however, as even a 1% concentration of fuel vapour would shift the lambda value by 20%. This is done by using a 'purge valve', which under some conditions is closed (full-load and idle for example) and can be progressively opened under other conditions. The system monitors the effect by use of the lambda sensor signal
Crankcase fumes (blow by)	Hydrocarbons become concentrated in the crankcase mostly due to pressure blowing past the piston rings. These gases must be conducted back into the combustion process. This is usually via the air intake system. This is described as positive crankcase ventilation



Figure 6.37 EGR valve(Source: Delphi Media)

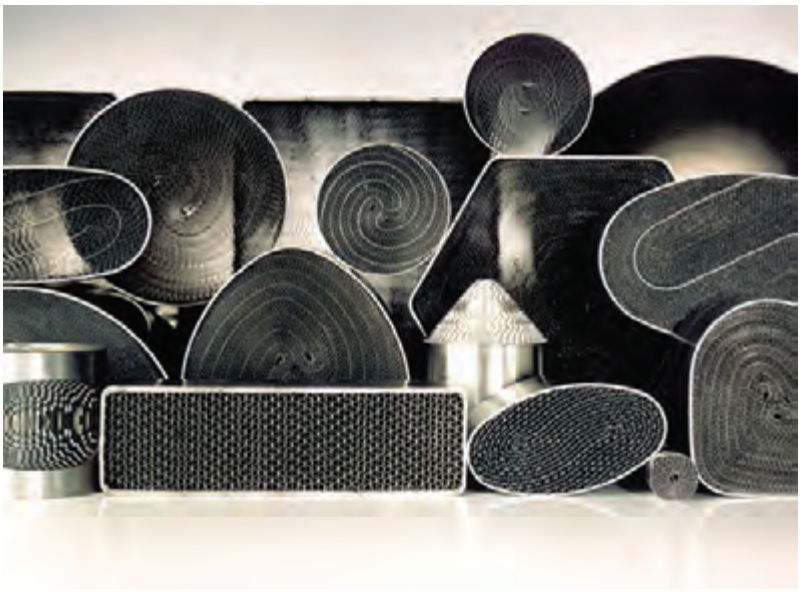


Figure 6.38 Catalytic converter metal substrates

6.9.2 Exhaust gas recirculation

Exhaust gas recirculation (EGR) is used primarily to reduce peak combustion temperatures and hence the production of nitrogen oxides (NO_x). EGR can be either internal due to valve overlap, or external via a simple arrangement of pipes and a valve (Figure 6.37 shows an example) connecting the exhaust manifold back to the inlet manifold. A proportion of exhaust gas is simply returned to the inlet side of the engine.

Key fact

Exhaust gas recirculation (EGR) is used primarily to reduce peak combustion temperatures and hence the production of nitrogen oxides (NO_x).

This process is controlled electronically as determined by a ROM in the ECU. This ensures that driveability is not affected and also that the rate of EGR is controlled. If the rate is too high, then the production of hydrocarbons increases.

One drawback of EGR systems is that they can become restricted by exhaust residue over a period of time, thus changing the actual percentage of recirculation. However, valves that reduce this particular problem are now available.

6.9.3 Catalytic converters

Stringent regulations in most parts of the world have made the use of a catalytic converter almost indispensable. The three-way catalyst (TWC) is used to great effect by most manufacturers. It is a very simple device and looks similar to a standard exhaust box. Note that in order to operate correctly, however, the engine must be run at or very near to stoichiometry. This is to ensure that the right 'ingredients' are available for the catalyst to perform its function.

Key fact

For a three-way catalyst (TWC) to operate correctly the engine must be run at or very near to stoichiometry.

Figure 6.38 shows some new metallic substrates for use inside a catalytic converter. There are many types of hydrocarbons, but the example illustrates the

main reaction. Note that the reactions rely on some CO being produced by the engine in order to reduce the NO_x. This is one of the reasons that manufacturers have been forced to run the engine at stoichiometry. The legislation has tended to stif e the development of lean burn techniques. The f ne details of the emission regulations can in fact have a very marked effect on the type of reduction techniques used. The main reactions in the 'cat' are as follows:

- Reduction of nitrogen oxides to nitrogen and oxygen:
 $2NO_x \rightarrow xO_2 + N_2$
- Oxidation of carbon monoxide to carbon dioxide:
 $2CO + O_2 \rightarrow 2CO_2$
- Oxidation of unburnt hydrocarbons (HC) to carbon dioxide and water:
 $C_xH_{2x+2} + [(3x + 1)/2]O_2 \rightarrow xCO_2 + (x + 1)H_2O$

Noble metals are used for the catalysts; platinum promotes the oxidation of HC and CO, and rhodium helps the reduction of NO_x. The whole three-way catalytic converter contains only about 3–4 g of the precious metals.

The ideal operating temperature range is from approximately 400 to 800 °C. A serious problem to counter is the delay in the catalyst reaching this temperature. This is known as catalyst light-off time. Various methods have been used to reduce this time as signif cant emissions are produced before light-off occurs. Electrical heating is one solution, as is a form of burner which involves lighting fuel inside the converter. Another possibility is positioning the converter as part of the exhaust manifold and down pipe assembly. This greatly reduces light-off time, but gas f ow problems, vibration and excessive temperature variations can be problems that reduce the potential life of the unit.

Catalytic converters can be damaged in two ways. The f rst is by the use of leaded fuel which causes lead compounds to be deposited on the active surfaces, thus reducing effective area. The second is engine misf re which can cause the catalytic converter to overheat due to burning inside the unit. BMW, for example, use a system on some vehicles where a sensor monitors output of the ignition HT system and will not allow fuel to be injected if the spark is not present.

For a catalytic converter to operate at its optimum conversion rate to oxidise CO and HC while reducing NO_x, a narrow band within 0.5% of lambda value 1 is essential. Lambda sensors in use at present tend to operate within approximately 3% of the lambda mean value. When a catalytic converter is in prime condition, this is not a problem due to storage capacity within the converter for CO and O_2. Damaged converters, however, cannot store suff cient quantity of these gases and hence become less eff cient. The damage as suggested earlier in this section can be due to overheating or by 'poisoning' due to lead or even silicon. If the control can be kept within 0.5% of lambda, the converter will continue to be effective even if damaged to some extent. Sensors which can work to this tolerance are becoming available. A second sensor f tted after the converter can be used to ensure ideal operation.



Figure 6.39 Catalytic converter ceramic substrates

6.10 Diagnostics – emissions

6.10.1 Testing procedure

If the reported fault is incorrect exhaust emissions, the procedure shown in Figure 6.40 should be utilized.

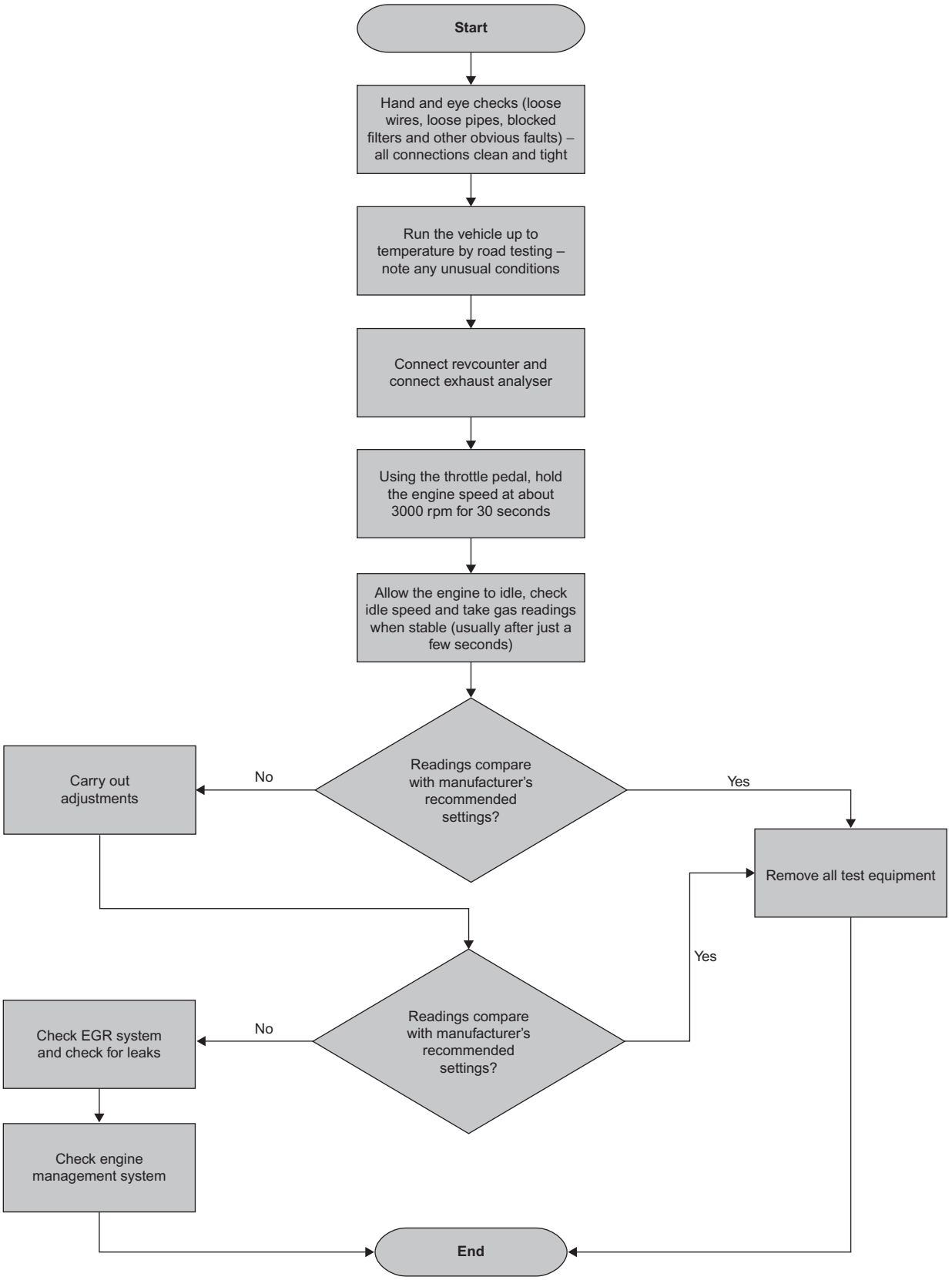


Figure 6.40 Emissions systems diagnosis chart

6.10.2 Emissions fault diagnosis table

Symptom	Possible cause
EGR valve sticking	Build-up of carbon Electrical fault
High CO and high HC	Rich mixture Blocked air filter Damaged catalytic converter Engine management system fault
Low CO and High HC	Misfire Fouled plug(s) Weak mixture
Low CO and low or normal HC	Exhaust leak Fouled injector

6.11 Fuel injection

6.11.1 Introduction

The ideal air fuel ratio is approximately 14.7:1. This is the theoretical amount of air required to completely burn the fuel. It is given a 'lambda (l)' value of 1.

Air fuel ratio is altered during the following operating conditions of an engine to improve its performance, driveability, consumption and emissions:

- **cold starting** – richer mixture is needed to compensate for fuel condensation and improve driveability;
- **load or acceleration** – richer to improve performance;
- **cruise or light loads** – weaker for economy;
- **overrun** – very weak (if any) fuel, to improve emissions and economy.

The more accurately the air fuel ratio is controlled to cater for external conditions, the better the overall operation of the engine.

The major advantage, therefore, of a fuel injection system is accurate control of the fuel quantity injected into the engine. The basic principle of fuel injection is that if petrol is supplied to an injector (electrically controlled valve), at a constant differential pressure, then the amount of fuel injected will be directly proportional to the injector open time.

Most systems are now electronically controlled even if containing some mechanical metering components. This allows the operation of the injection system to be very closely matched to the requirements of the engine. This matching process is carried out during development on test beds and dynamometers, as well as development in the car. The ideal operating data for a large number of engine operating conditions is stored in a ROM in the ECU. Close control of fuel quantity injected allows the optimum setting for mixture strength when all operating factors are taken into account (Figure 6.41).

Further advantages of electronic fuel injection control are that overrun cut-off can easily be implemented, fuel can be cut at the engines rev limit and information on fuel used can be supplied to a trip computer (Figure 6.42).

Definition

λ = actual air quantity÷theoretical air quantity.

Key fact

The major advantage of a fuel injection system is accurate control of the fuel mixture.

Mazda 626 2.01 GX 16 valve		
Adjustment Data (Fuel)		
DESCRIPTION	SETTING	UNITS
Carburettor/injection make	Mazda	
Carburettor/injection type	MPI	
Fuel pump pressure	5.10 ± 0.70	bar
Injection pressure	1.50	bar
Idle speed	700 ± 50	rev/min
Raised idle speed	Not applicable	rev/min
CO at idle speed	0.50 maximum	%
Carbon dioxide at idle speed	14.50/16.00	%
HC at idle speed	100	ppm
Oxygen at idle speed	0.10/0.50	%

Figure 6.41 Adjustment and emissions data example

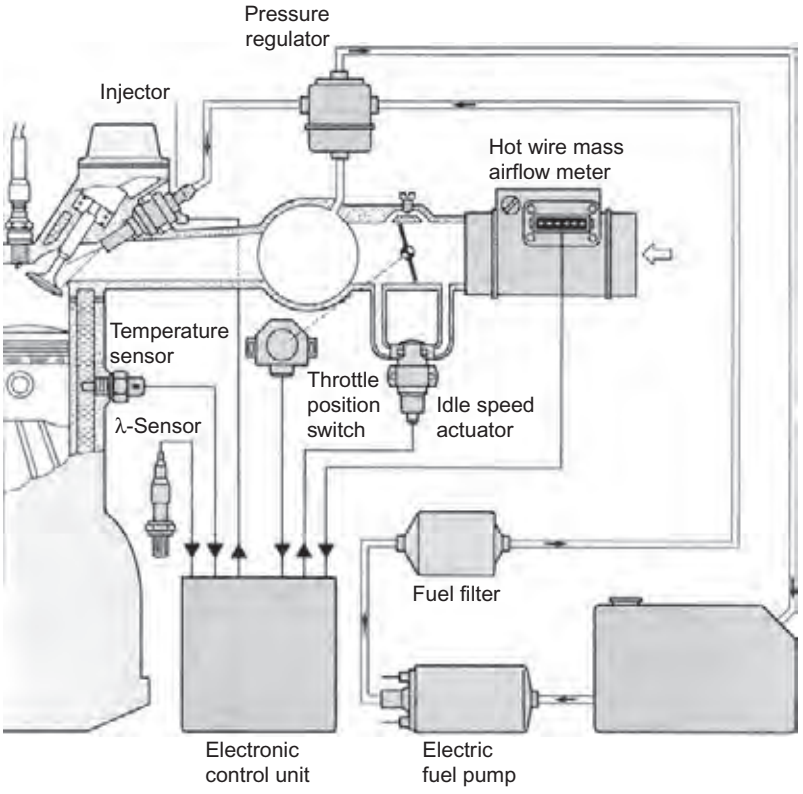


Figure 6.42 Fuel injection system layout

6.11.2 Injection systems

Fuel injection systems can be classif ed into two main categories: single-point injection and multipoint injection. Figure 6.43 shows these techniques. Depending on the sophistication of the system, idle speed and idle mixture adjustment can be either mechanically or electronically controlled.

Figure 6.44 shows a block diagram of inputs and outputs common to most fuel injection systems. Note that the two most important input sensors to the system are speed and load. The basic fuelling requirement is determined from these inputs in a similar way to the determination of ignition timing.

An engine's fuelling requirements are stored as part of a ROM chip in the ECU. When the ECU has determined the 'lookup value' of the fuel required (injector open time), corrections to this f gure can be added for battery voltage, temperature, throttle change or position and fuel cut-off. Figure 6.45 shows an injection system ECU.

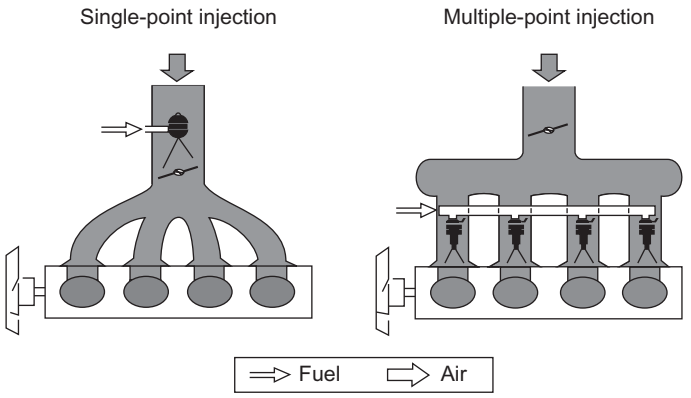


Figure 6.43 Injection methods

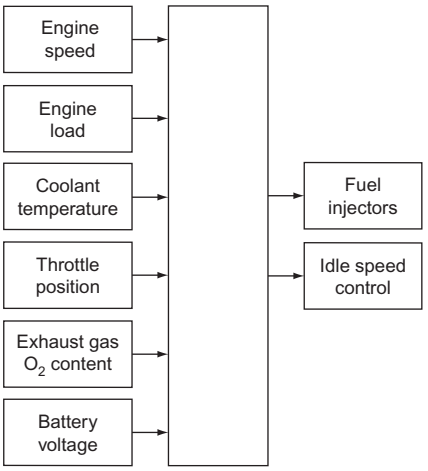


Figure 6.44 Fuel injection simplified block diagram

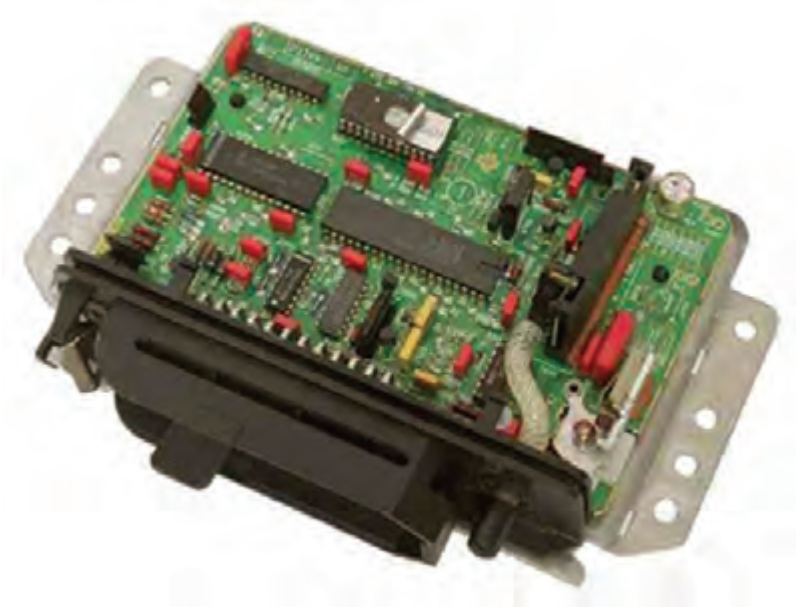


Figure 6.45 Engine management ECU

Idle speed and fast idle are also generally controlled by the ECU and a suitable actuator. It is also possible to have a form of closed-loop control with electronic fuel injection. This involves a lambda sensor to monitor exhaust gas oxygen content. This allows very accurate control of the mixture strength, as the oxygen content of the exhaust is proportional to the air fuel ratio. The signal from the lambda sensor is used to adjust the injector open time.

Key fact

A lambda sensor monitors exhaust gas oxygen content.

6.11.3 Fuel injection components

Many of the sensors and actuators associated with fuel injection are covered in Chapter 4. Figure 6.46 shows those associated with an earlier Motronic injection system. The main fuel components are outlined below:

Airf ow meter

The type shown is a hot-wire meter. This allows direct measurement of air mass as temperature compensation is built in. The air quantity helps to determine the fuel required.



Figure 6.46 Earlier Motronic system components

Electronic control unit (ECU)

This is also referred to as the electronic control module (ECM). The circuitry to react to the sensor signals by controlling the actuators is in the ECU. The data is stored in ROM.

Fuel pump

Pressurised fuel is supplied to the injectors. Most pumps work on the centrifugal roller principle. The pump ensures a constant supply of fuel to the fuel rail. The volume in the rail acts as a swamp to prevent pressure f uctuations as the injectors operate. The pump must be able to maintain a pressure of approximately 3 bar.

Fuel f lter

The fuel supplied to the injectors must be free from any contamination or else the injector nozzle will be damaged or blocked.

Lambda sensor

The quantity of oxygen in the exhaust, when accurately measured, ensures that the fuel air mixture is kept within the lambda window (0.97–1.03).

Temperature sensor

A simple thermistor is used to determine the engine coolant temperature.

Fuel injectors

These are simple solenoid-operated valves designed to operate very quickly and produce a f nely atomised spray pattern.

Idle or fast idle control actuator

The rotary actuator is used to provide extra air for cold fast idle conditions and to control idle speed. It is supplied with a variable duty cycle square wave.

Fuel pressure regulator

This device is to ensure a constant differential pressure across the injectors. It is a mechanical device and has a connection to the inlet manifold.

Throttle position switch

This is used to supply information as to whether the throttle is at idle, full load or somewhere in between.

6.11.4 Fuel mixture calculation



Key fact

The quantity of fuel needed is determined by the mass of air drawn into the engine.

The quantity of fuel to be injected is determined primarily by the quantity of air drawn into the engine. This is dependent on two factors:

1. engine speed (rpm);
2. engine load (inlet manifold pressure).

This speed load characteristic is held in the ECU memory in ROM lookup tables.

A sensor connected to the manifold by a pipe senses manifold absolute pressure. The sensor is fed with a stabilised 5 V supply and transmits an output voltage according to the pressure. The sensor is f tted away from the manifold and hence a pipe is required to connect it. The output signal varies between approximately 0.25 V at 0.17 bar to approximately 4.75 V at 1.05 bar. The density of air varies with temperature such that the information from the MAP sensor on air quantity will be incorrect over wide temperature variations. An air temperature sensor is used to inform the ECU of the inlet air temperature such that the quantity of fuel injected may be corrected. As the temperature of air decreases, its density increases and hence the quantity of fuel injected must also be increased. The other method of sensing engine load is direct measurement of air intake quantity using a hot-wire meter or a f ap-type airf ow meter.

To operate the injectors, the ECU needs to know, in addition to air pressure, the engine speed to determine the injection quantity. The same f ywheel sensor used by the ignition system provides this information. All four injectors operate simultaneously once per engine revolution, injecting half of the required fuel. This helps to ensure balanced combustion. The start of injection varies according to ignition timing.

A basic open period for the injectors is determined by using the ROM information relating to manifold pressure and engine speed. Two corrections are then made, one relative to air temperature and another depending on whether the engine is idling, at full or partial load.

The ECU then carries out another group of corrections, if applicable:

- after-start enrichment;
- operational enrichment;
- acceleration enrichment;
- weakening on deceleration;
- cut-off on overrun;
- reinstatement of injection after cut-off;
- correction for battery voltage variation.

Under starting conditions, the injection period is calculated differently. This is determined mostly from a set f gure varied as a function of temperature.

The coolant temperature sensor is a thermistor and is used to provide a signal to the ECU relating to engine coolant temperature. The ECU can then calculate any corrections to fuel injection and ignition timing. The operation of this sensor is the same as the air temperature sensor.

The throttle potentiometer is f xed on the throttle butterf y spindle and informs the ECU of throttle position and rate of change of throttle position. The sensor provides information on acceleration, deceleration and whether the throttle is in the full-load or idle position. It comprises a variable resistance and a f xed resistance. As is common with many sensors, a f xed supply of 5 V is provided and the return signal will vary approximately between 0 and 5 V. The voltage increases as the throttle is opened.

6.12 Diagnostics – fuel injection systems

6.12.1 Testing procedure

Safety f rst

Warning: Caution/Achtung/ Attention – Burning fuel can seriously damage your health.

The following procedure is generic and with a little adaptation can be applied to any fuel injection system. Refer to manufacturer's recommendations if in any doubt. It is assumed that the ignition system is operating correctly. Most tests are carried out while cranking the engine.

6.12.2 Fuel injection fault diagnosis table

Symptom	Possible fault
Engine rotates but does not start	No fuel in the tank! Air filter dirty or blocked Fuel pump not running No fuel being injected
Difficult to start when cold	Air filter dirty or blocked Fuel system wiring fault Enrichment device not working Coolant temperature sensor short circuit
Difficult to start when hot	Air filter dirty or blocked Fuel system wiring fault Coolant temperature sensor open circuit
Engine starts but then stops immediately	Fuel system contamination Fuel pump or circuit fault (relay) Intake system air leak
Erratic idle	Air filter blocked Inlet system air leak Incorrect CO setting Idle air control valve not operating Fuel injectors not spraying correctly
Misfire through all speeds	Fuel filter blocked Fuel pump delivery low Fuel tank ventilation system blocked

(*Continued*)

Symptom	Possible fault
Engine stalls	Idle speed incorrect CO setting incorrect Fuel filter blocked Air filter blocked Intake air leak Idle control system not working
Lack of power	Fuel filter blocked Air filter blocked Low fuel pump delivery Fuel injectors blocked
Backfires	Fuel system fault (airflow sensor on some cars) Ignition timing

6.13 Diesel injection

6.13.1 Introduction

The basic principle of the four-stroke diesel engine is very similar to the petrol system. The main difference is that the mixture formation takes place in the cylinder combustion chamber as the fuel is injected under very high pressure. The timing and quantity of the fuel injected is important from the usual issues of performance, economy and emissions (Figure 6.47).

Fuel is metered into the combustion chamber by way of a high-pressure pump connected to injectors via heavy-duty pipes. When the fuel is injected, it mixes with the air in the cylinder and will self-ignite at approximately 800 °C. The mixture formation in the cylinder is influenced by the following factors.

The timing of a diesel fuel injection pump to an engine is usually done using start of delivery as the reference mark. The actual start of injection, in other words when fuel starts to leave the injector, is slightly later than the start of delivery, as this is influenced by the compression ratio of the engine, the compressibility of the fuel and the length of the delivery pipes. This timing has a great effect on the production of carbon particles (soot), if too early, and increases the hydrocarbon emissions, if too late.

The duration of the injection is expressed in degrees of crankshaft rotation in milliseconds. This clearly influences fuel quantity, but the rate of discharge is also important. This rate is not constant due to the mechanical characteristics of the injection pump.

Pressure of injection will affect the quantity of fuel, but the most important issue here is the effect on atomisation. At higher pressures, the fuel will atomise into smaller droplets with a corresponding improvement in the burn quality. Indirect injection systems use pressures up to approximately 350 bar and direct injection systems can be up to approximately 1000 bar. Emissions of soot are greatly reduced by higher-pressure injection.

The direction of injection must match very closely the swirl and combustion chamber design. Deviations of only 2° from the ideal can greatly increase particulate emissions.

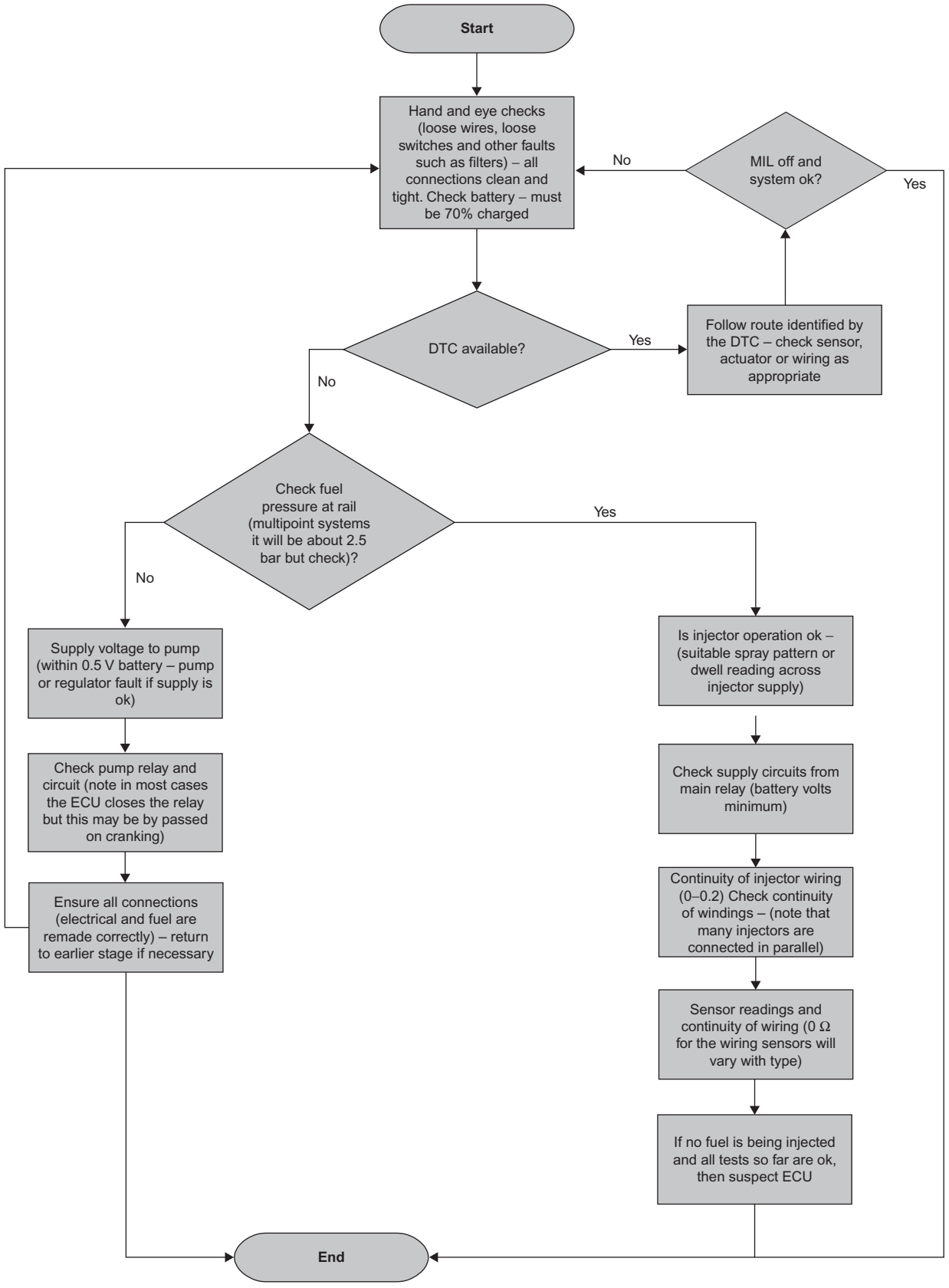


Figure 6.47 Fuel injection system diagnosis chart

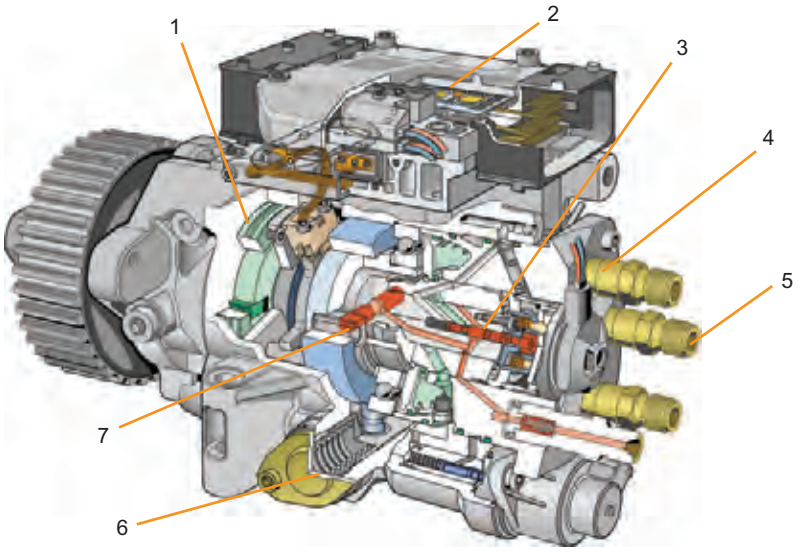


Figure 6.48 Solenoid-valve controlled radial-piston distributor pump: 1– sensor (position/timing); 2 – ECU; 3 – high-pressure solenoid valve needle; 4 – solenoid; 5 – outlets to injectors; 6 – timing device (ignition advance mechanism); 7 – radial-piston high-pressure pump (Source: Bosch Media)

Diesel engines do not in general use a throttle butterf y, as the throttle acts directly on the injection pump to control fuel quantity. At low speeds in particular the very high excess air factor ensures complete burning and very low emissions. Diesel engines operate where possible with an excess air factor even at high speeds.

Figure 6.48 shows a typical diesel fuel injection pump. Detailed operation of the components is beyond the scope of this book. The principles and problems are the issues under consideration, in particular the way electronics can be employed to solve some of the problems.

6.13.2 Electronic control of diesel injection

The advent of electronic control over the diesel injection pump has allowed many advances over the purely mechanical system. The production of high pressure for injection is, however, still mechanical with all current systems. The following advantages are apparent over the non-electronic control system:

- more precise control of fuel quantity injected;
- better control of start of injection;
- idle speed control;
- control of EGR;
- drive by wire system (potentiometer on throttle pedal);
- an anti-surge function;
- output to data acquisition systems, etc.;
- temperature compensation;
- cruise control.

Because fuel must be injected at high pressure, the hydraulic head, pressure pump and drive elements are still used. An electromagnetic moving iron actuator adjusts the position of the control collar, which in turn controls the delivery stroke and therefore the injected quantity of fuel. Fuel pressure is applied to a roller

Key fact

Electronic control of diesel injection has allowed many advances over the purely mechanical system.

ring and this controls the start of injection. A solenoid-operated valve controls the supply to the roller ring. These actuators together allow control of start of injection and injection quantity.

Ideal values for fuel quantity and timing are stored in memory maps in the ECU. The injected fuel quantity is calculated from the accelerator position and the engine speed. Start of injection is determined from the following:

- fuel quantity;
- engine speed;
- engine temperature;
- air pressure.

The ECU is able to compare start of injection with actual delivery from a signal produced by the needle motion sensor in the injector.

Control of EGR is a simple solenoid valve. This is controlled as a function of engine speed, temperature and injected quantity. The ECU is also in control of the stop solenoid and glow plugs via a suitable relay.

6.13.3 Common rail diesel systems

Key fact

Common rail diesel injection operates at very high injection pressures and has piloted and phased injection to reduce noise and vibration.

The development of diesel fuel systems is continuing, with many new electronic changes to the control and injection processes. One of the latest developments is the 'common rail' system, operating at very high injection pressures. It also has piloted and phased injection to reduce noise and vibration (Figure 6.49).

The common rail system has made it possible, on small, high-speed diesel engines, to have direct injection, whereas previously they would have been of indirect injection design. These developments are showing improvements in fuel consumption and performance of up to 20% over the earlier indirect injection engines of a similar capacity. The common rail injection system can be used on the full range of diesel engine capacities.

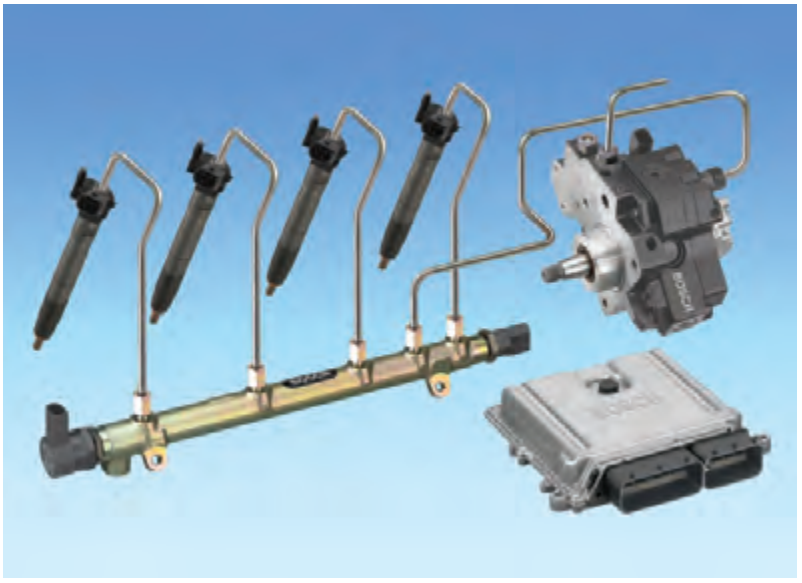


Figure 6.49 Common rail diesel system components (Source: Bosch Media)

The combustion process, with common rail injection, is improved by a pilot injection of a very small quantity of fuel, at between 40° and 90° BTDC. This pilot fuel ignites in the compressing air charge so that the cylinder temperature and pressure are higher than in a conventional diesel injection engine at the start of injection. The higher temperature and pressure reduce ignition lag to a minimum, so that the controlled combustion phase during the main injection period is softer and more eff cient (Figure 6.50).

Fuel injection pressures are varied – throughout the engine speed and load range – to suit the instantaneous conditions of driver demand and engine speed and load conditions. Data input from other vehicle system ECUs is used to further adapt the engine output, to suit changing conditions elsewhere on the vehicle. Examples are traction control, cruise control and automatic transmission gearshifts.

The electronic diesel control (EDC) module carries out calculations to determine the quantity of fuel delivered. It also determines the injection timing based on engine speed and load conditions.

The actuation of the injectors, at a specif c crankshaft angle, and for a specif c duration, is made by signal currents from the EDC module. A further function of the EDC module is to control the accumulator (rail) pressure.

In summary, common rail diesel fuel injection systems consist of four main component areas:

- low-pressure delivery;
- high-pressure delivery with a high-pressure pump and accumulator (the rail);
- electronically controlled injectors (Figure 6.51);
- electronic control unit and associated sensors and switches.

The main sensors for calculation of the fuel quantity and injection advance requirements are the accelerator pedal sensor, crankshaft speed and position sensor, air mass meter and the engine coolant temperature sensor.

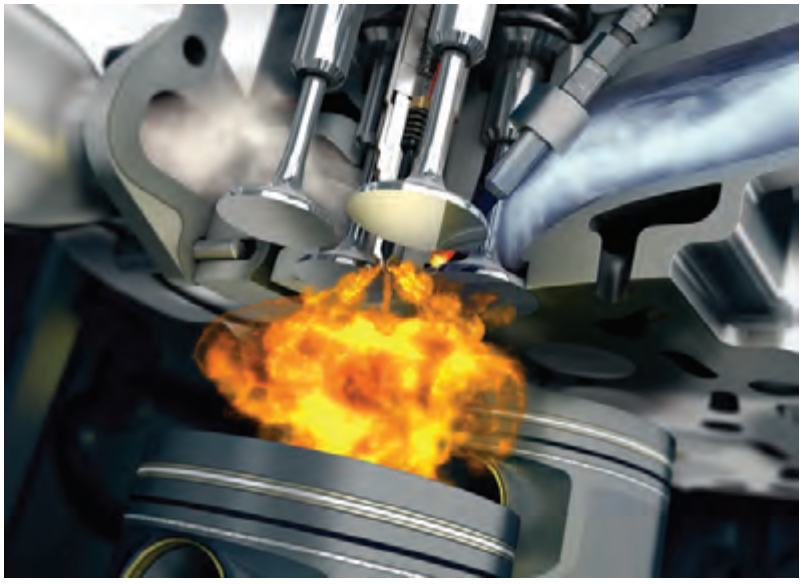


Figure 6.50 Common rail diesel combustion

6.13.4 Diesel exhaust emissions

Exhaust emissions from diesel engines have been reduced considerably by changes in the design of combustion chambers and injection techniques.

More accurate control of start of injection and spill timing has allowed further improvements to be made. Electronic control has also made a signif cant contribution. A number of further techniques can be employed to control emissions.

Key fact

Overall, the gas emissions from diesel combustion are lower than those from petrol combustion; the main problem area is that of particulates.

Overall, the gas emissions from diesel combustion are far lower than those from petrol combustion. The CO, HC and NO_x emissions are lower mainly due to the higher compression ratio and excess air factor. The higher compression ratio improves the thermal eff ciency and thus lowers the fuel consumption. The excess air factor ensures more complete burning of the fuel.

The main problem area is that of particulate emissions. These particle chains of carbon molecules can also contain hydrocarbons, aldehydes mostly. The dirt effect of this emission is a pollution problem, but the possible carcinogenic effect of this soot gives cause for concern. The diameter of these particles is only a few ten thousandths of a millimetre. This means they f oat in the air and can be inhaled.

In much the same way as with petrol engines, EGR is employed primarily to reduce NO_x emissions by reducing the reaction temperature in the combustion chamber. However, if the percentage of EGR is too high, increased hydrocarbons and soot are produced. This is appropriate to turbocharged engines such that if the air is passed through an intercooler and there are improvements in volumetric eff ciency, lower temperature will again reduce the production of NO_x. The intercooler is f tted in the same way as the cooling system radiator.

6.13.5 Catalytic converter diesel

On a diesel engine, a catalyst can be used to reduce the emission of hydrocarbons but will have less effect on nitrogen oxides. This is because diesels are always run with excess air to ensure better and more eff cient burning of the fuel. A normal catalyst therefore will not strip the oxygen off the NO to oxidise the

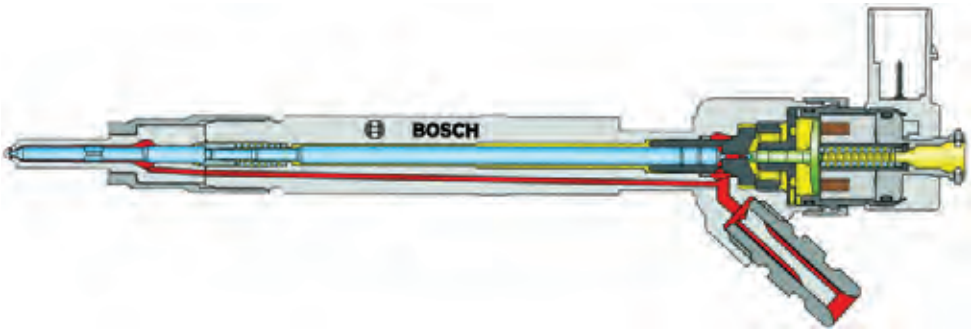


Figure 6.51 Electrically operated diesel fuel injector

hydrocarbons because the excess oxygen will be used. Special NO_x converters are becoming available.

6.13.6 Filters

To reduce the emission of particulate matter (soot), f lters can be used. These can vary from a f ne grid design made from a ceramic material to centrifugal f lters and water trap techniques. The problem to overcome is that the f lters can get blocked, which adversely affects the overall performance. Several techniques are employed including centrifugal f lters.

6.14 Diagnostics – diesel injection systems

6.14.1 Test equipment

Safety f rst

Note: You should always refer to the manufacturer's instructions appropriate to the equipment you are using.

Smoke meter

The smoke meter is an essential device in the United Kingdom and other countries where the level of smoke in the exhaust forms part of the annual test. Most devices use infrared light to 'count' the number of soot particles in the exhaust sample. This particulate matter is highly suspected of being carcinogenic (Figure 6.52).

Injector tester

The pressure required to 'crack' (lift the nozzle) on an injector can be tested (Figure 6.53).



Figure 6.52 Gas analyser and smoke meter



Figure 6.53 Injector pop tester

6.14.2 Diesel injection fault diagnosis table

Symptom	Possible fault
Engine rotates but does not start	No fuel in the tank! Cam belt broken Fuel pump drive broken Open circuit supply to stop solenoid Fuel filter blocked
Excessive smoke	Refer to the next section
Lack of power	Timing incorrect Governor set too low Injector nozzles worn Injector operating pressure incorrect
Difficult to start	Timing incorrect Glow plugs not working
Fuel smell in the car	Fuel lines leaking Leak off pipes broken
Diesel knock (particularly when cold)	Timing incorrect Glow plug hold on for idle circuit not working
Engine oil contaminated with fuel	Piston broke (like me after a good holiday!) Work piston rings Excessive fuel injected

6.14.3 Diesel engine smoke

Diesel fuel is a hydrocarbon fuel. When it is burned in the cylinder, it will produce carbon dioxide and water. There are, however, many circumstances under which the fuel may not be completely burned and one of the results is smoke. Despite the fact that diesel engines are designed to run under all conditions with an excess of air, problems still occur. Very often, these smoke problems are easily

avoided by proper maintenance and servicing of the engine and its fuel system. The emission of smoke is usually due to a shortage of air (oxygen). If insuff cient air is available for complete combustion, then unburnt fuel will be exhausted as tiny particles of fuel (smoke).

The identif cation of the colour of diesel smoke and under what conditions it occurs can be helpful in diagnosing what caused it in the f rst place. Poor-quality fuel reduces engine performance, increases smoke and reduces engine life. There are three colours of smoke: white, blue and black. All smoke diagnosis tests must be carried out with the engine at normal operating temperature.

White or grey smoke

White smoke is vaporised unburnt fuel and is caused by there being suff cient heat in the cylinder to vaporise it but not enough remaining heat to burn it. All diesel engines generate white smoke when starting from cold and it is not detrimental to the engine in any way – it is a diesel characteristic. Possible causes of white smoke are listed below:

- **Faulty cold starting equipment** – Cold engines suffer from a delay in the combustion process. A cold start unit is f tted to advance the injection timing to counteract this delay. This means that white smoke could be a cold start unit problem.
- **Restrictions in the air supply** – A partially blocked air cleaner will restrict the air supply – an easy cause to rectify but often overlooked. Incidentally, a blocked air cleaner element at light load in the workshop becomes a black smoke problem when the engine is under load. In both cases, there will not be suff cient air entering the cylinder for the piston to compress and generate full heat for combustion.
- **Cold running** – Check the cooling system thermostat to see if the correct rated thermostat is f tted.
- **Incorrect fuel injection pump timing** – If fuel is injected late (retarded timing), it may be vaporised but not burned.
- **Poor compressions** – Poor compressions may lead to leakage during the compression stroke and inevitably less heat would be generated.
- **Leaking cylinder head gasket** – If coolant were leaking into the combustion area, the result would be less temperature in the cylinder causing white smoke. Steam may also be generated if the leak is suff cient. All internal combustion engines have water as a by-product from burning fuel – you will have noticed your own car exhaust, especially on a cold morning.

Blue smoke

Blue smoke is almost certainly a lubricating oil burning problem. Possible causes of blue smoke are listed:

- incorrect grade of lubricating oil;
- worn or damaged valve stem oil seals, valve guides or stems where lubricating oil is getting into the combustion chamber;
- worn or sticking piston rings;
- worn cylinder bores.

Black smoke

Black smoke is partly burned fuel. Possible causes are listed below:

- **Restriction in air intake system** – A blocked air cleaner element will not let enough air in to burn all the fuel.

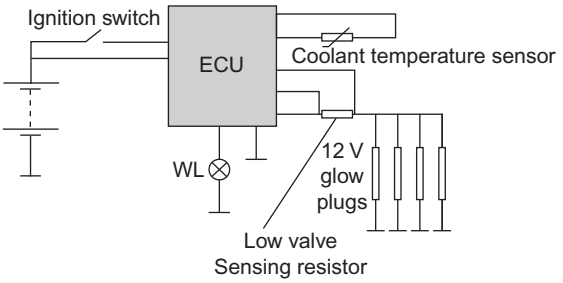


Figure 6.54 Glow plug circuit

- **Incorrect valve clearances** – Excessive valve clearances will cause the valves not to fully open and to close sooner. This is another form of insuff cient air supply.
- **Poor compressions** – Air required for combustion may leak from the cylinder.
- **Defective or incorrect injectors** – Check the injector to see if the spray is fully atomised and solid fuel is not being injected.
- **Incorrect fuel injection pump timing** – This is less likely because the timing would need to be advanced to the point where additional engine noise would be evident.
- **Low boost pressure** – If a turbocharger is f tted and is not supplying enough air for the fuel injected, this is another form of air starvation.

6.14.4 Glow plug circuit

Figure 6.54 shows a typical glow plug circuit controlled by an ECU. Most timer circuits put the glow plugs on for a few seconds before cranking. A warning light may be used to indicate the 'ready' condition to the driver.

Take care to note the type of glow plugs used; most are 12 V and connected in parallel, but some are connected in series (4 – 3 V plugs). To check the operation of most 12 V glow plug circuits, use the following steps:

1. Hand and eye checks.
2. Battery condition – at least 70%.
3. Engine must be cold – it may be possible to simulate this by disconnecting the temperature sensor.
4. Voltage supplied to plugs when ignition is switched on (spring-loaded position in some cases) – 10–12 V.
5. Warning light operation – should go out after a few seconds.
6. Voltage supplied to plugs while cranking – 9–11 V.
7. Voltage supplied to plugs after engine has started – 0 V or if silent idle system is used 5–6 V for several minutes.
8. Same tests with engine at running temperature – glow plugs may not be energised or only for the starting phase.

6.14.5 Diesel systems

It is recommended that when the injection pump or the injectors are diagnosed as being at fault, reconditioned units should be f tted. Other than basic settings of timing, idle speed and governor speed, major overhaul is often required. Figure 6.55 shows a general diagnosis pattern for diesel systems.

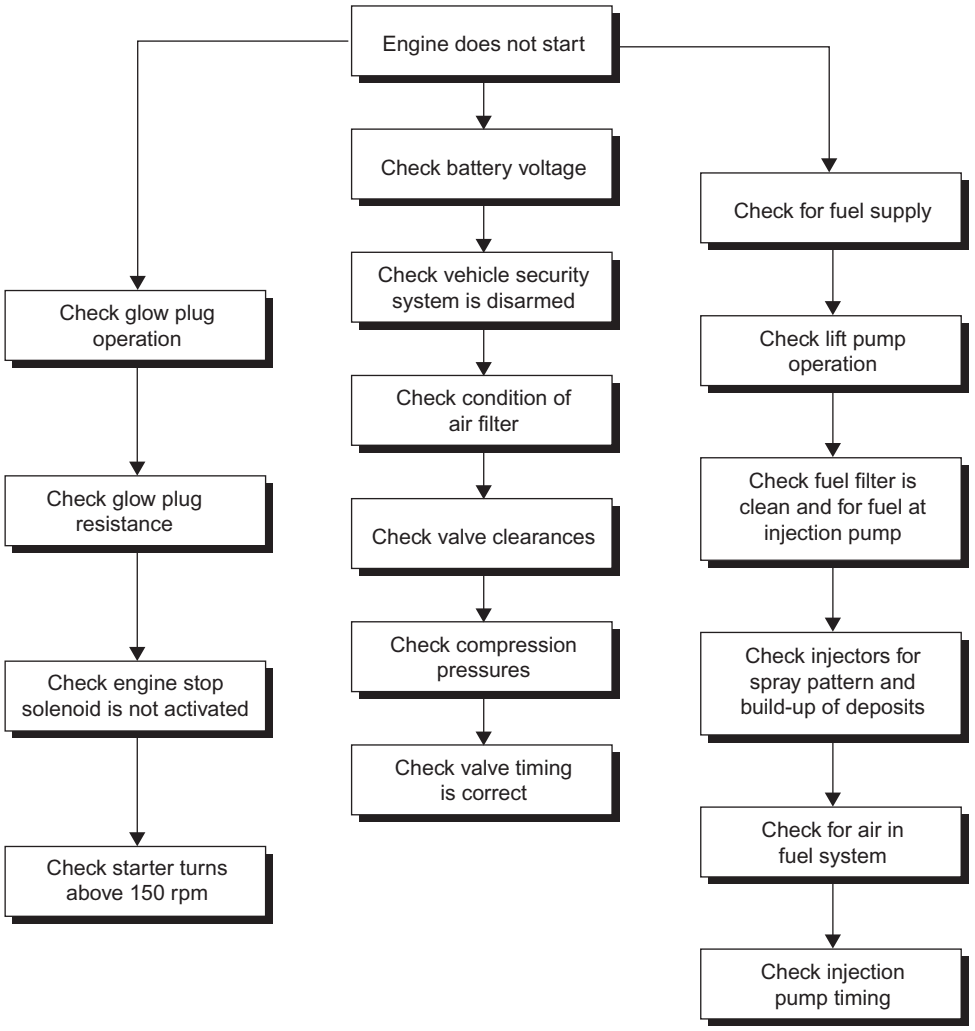


Figure 6.55 Diesel system generic diagnostic process

6.15 Engine management

6.15.1 Introduction

As the requirement for lower and lower emissions continues together with the need for better performance, other areas of engine control are constantly being investigated. This is becoming even more important as the possibility of carbon dioxide emissions being included in the regulations increases. Some of the current and potential areas for further control of engine operation are included in this section. Most of the common aspects have been covered earlier in the 'Ignition' and 'Fuel injection' sections. The main areas of control are as follows:

- ignition timing;
- dwell angle;
- fuel quantity;
- idle speed.

Further areas of engine control may include the following:

- EGR;
- canister purge;

- valve timing;
- inlet manifold length;
- closed-loop lambda control.

It is not possible for an engine to operate at its best volumetric eff ciency with f xed manifolds. This is because the length of the inlet tract determines the velocity of the intake air and in particular the propagation of the pressure waves set up by the pumping action of the cylinders. These standing waves can be used to improve the ram effect of the charge as it enters the cylinder but only if they coincide with the opening of the inlet valves. The length of the inlet tract has an effect on the frequency of these waves.

With the widespread use of twin-cam engines, one cam for the inlet valves and one for the exhaust valves, it is possible to vary the valve overlap while the engine is running. Honda has a system that improves the power and torque range by opening both of the inlet valves only at higher speed.

Many systems use oil pressure controlled by valves to turn the cam with respect to its drive gear. This alters the cam phasing or relative position. The position of the cams is determined from a suitable map held in ROM in the control unit.

6.15.2 Closed-loop lambda control

Current regulations have almost made closed-loop control of air fuel mixture in conjunction with a three-way catalytic converter mandatory. Lambda control is a closed-loop feedback system in that the signal from a lambda sensor in the exhaust can directly affect the fuel quantity injected. The lambda sensor is described in more detail in Chapter 4.

A graph to show the effect of lambda control in conjunction with a catalytic converter is shown in Figure 6.56. The principle of operation is as follows: the lambda sensor produces a voltage which is proportional to the oxygen content of the exhaust which is in turn proportional to the air fuel ratio. At the ideal setting, this voltage is approximately 450 mV. If the voltage received by the ECU is below this value (weak mixture), the quantity of fuel injected is increased slightly. If the signal voltage is above the threshold (rich mixture), the fuel quantity is reduced. This alteration in air fuel ratio must not be too sudden, as it could cause the engine to buck. To prevent this, the ECU contains an integrator, which changes the mixture over a period of time.

Key fact

Lambda control is a closed-loop negative feedback system.

A delay also exists between the mixture formation in the manifold and the measurement of the exhaust gas oxygen. This is due to the engine's working cycle and the speed of the inlet mixture, the time for the exhaust to reach the sensor and the sensor's response time. This is sometimes known as dead time and can be as much as one second at idle speed but only a few hundred milliseconds at higher engine speeds.

Def nition

TWC: Three-way catalyst.

Owing to the dead time, the mixture cannot be controlled to an exact value of lambda equals 1. If the integrator is adjusted to allow for engine speed, then it is possible to keep the mixture in the lambda window (0.97–1.03), which is the region in which the TWC is at its most eff cient.

Key fact

The lambda window (0.97–1.03) is the region in which the TWC is at its most effcient.

6.15.3 Engine management operation

The combination of ignition and injection control has several advantages. The information received from various sensors is used for computing both fuelling

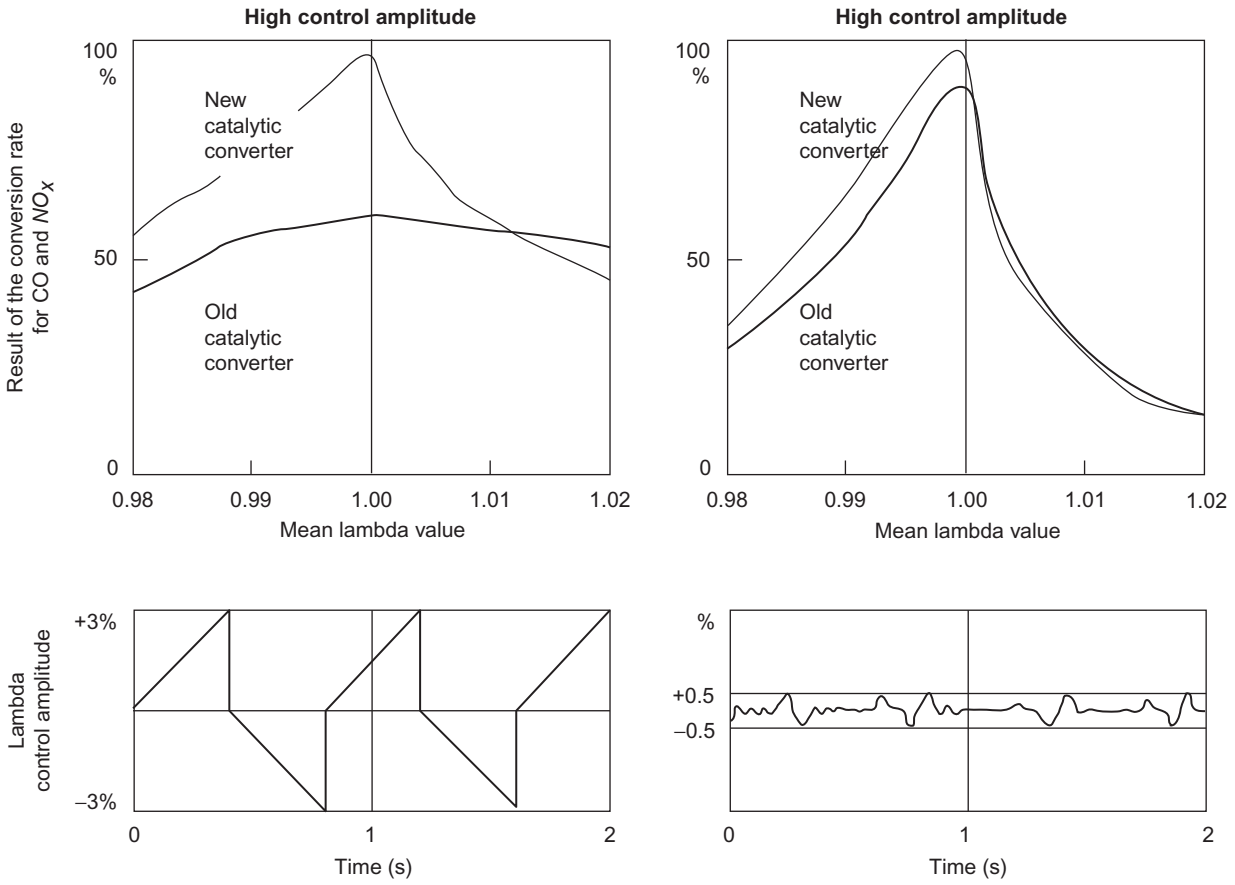


Figure 6.56 Effect of lambda control on catalytic converters

and ignition requirements. Perhaps more importantly ignition and injection are closely linked. The inf uence they have on each other can be easily taken into account to ensure that the engine is working at its optimum, under all operating conditions.

Overall, this type of system is less complicated than separate fuel and ignition systems and in many cases the ECU is able to work in an emergency mode by substituting missing information from sensors with pre-programmed values. This will allow limited but continued operation in the event of certain system failures.

The ignition system is integrated and is operated without a high-tension (HT) distributor. The ignition process is controlled digitally by the ECU. The data for the ideal characteristics are stored in ROM from information gathered during both prototyping and development of the engine. The main parameters for ignition advance are engine speed and load, but greater accuracy can be achieved by taking further parameters into account such as engine temperature. This provides both optimum output and close control of anti-pollution levels. Performance and pollution level control means that the actual ignition point must be in many cases a trade-off between the two.

The injection system shown in Figure 6.57 is multipoint and, as is the case for all fuel systems, the amount of fuel delivered is primarily determined by the amount of air 'drawn' into the engine. The method for measuring this data is indirect in the case of this system as a pressure sensor is used to determine the air quantity.

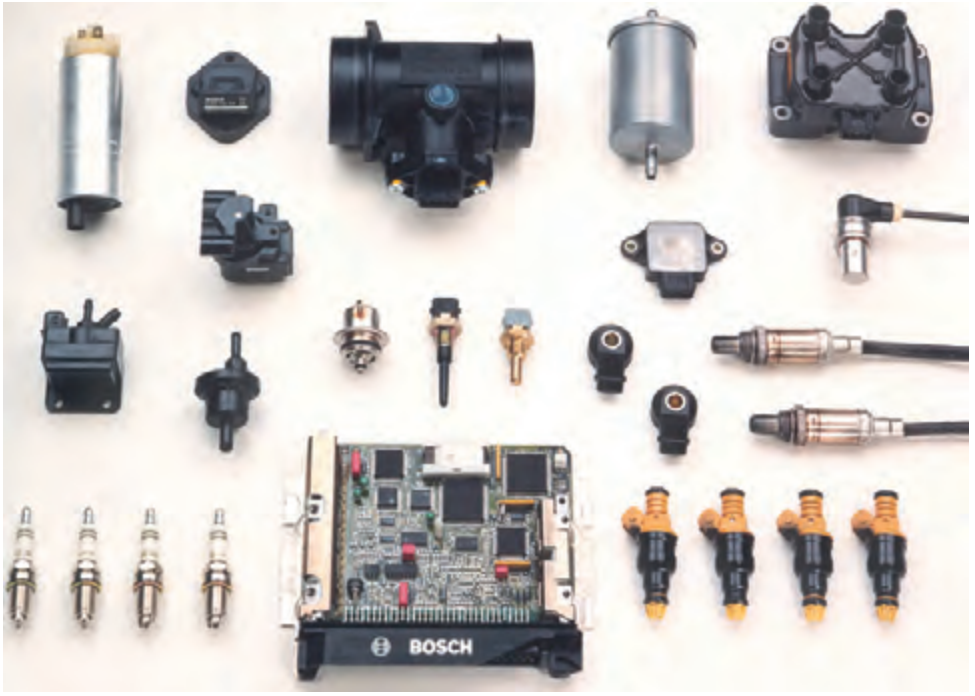


Figure 6.57 Engine management components (Source: Bosch Media)

Key fact

Injector open period is determined by the ECU.

Electromagnetic injectors control fuel supply into the engine. The injector open period is determined by the ECU. This will obtain very accurate control of the air fuel mixture under all operating conditions of the engine. The data for this is stored in ROM in the same way as for the ignition.

The main source of reference for the ignition system is from the crankshaft position sensor. This is a magnetic inductive pick-up sensor positioned next to a f ywheel ring containing 58 teeth. Each tooth takes up a 6° angle of the f ywheel with one 12° gap positioned 114° before top dead centre (BTDC) for number 1 cylinder. The signal produced by the f ywheel sensor is essentially a sine wave with a cycle missing corresponding to the gap in the teeth of the reluctor plate. The information provided to the ECU is engine speed from the frequency of the signal and engine position from the number of pulses before or after the missed pulses.

The basic ignition advance angle is obtained from a memorised cartographic map. This is held in a ROM chip within the ECU. The parameters for this are

- **engine rpm** – given by the f ywheel sensor;
- **inlet air pressure** – given by the MAP sensor.

The above two parameters (speed and load) give the basic setting, but to ensure optimum advance angle the timing is corrected by

- coolant temperature;
- air temperature;
- throttle butterf y position.

The ignition is set to a predetermined advance during the starting phase. Figure 6.58 shows typical advance, fuelling and dwell maps used by an engine management system. This data is held in ROM.

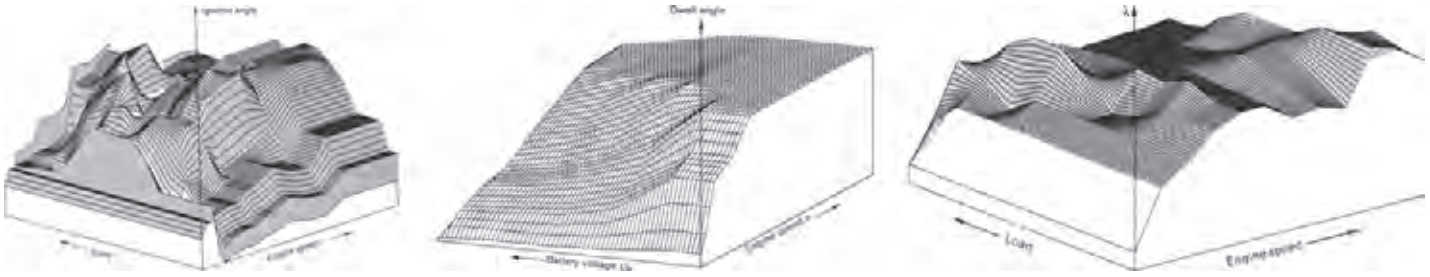


Figure 6.58 Ignition timing, dwell and lambda maps

For full ignition control, the electronic control unit has to first determine the basic timing for three different conditions:

- Under idling conditions, ignition timing is often moved very quickly by the ECU in order to control idle speed. When timing is advanced, engine speed will increase within certain limits.
- Full-load conditions require careful control of ignition timing to prevent combustion knock. When a full-load signal is sensed by the ECU (high manifold pressure), the ignition advance angle is reduced.
- Partial throttle is the main area of control and, as already stated, the basic timing is set initially by a programme as a function of engine speed and manifold pressure.

Corrections are added according to

- operational strategy;
- knock protection;
- phase correction.

The ECU will also control ignition timing variation during overrun fuel cut-off and reinstatement and also to ensure anti-jerk control. When starting the ignition timing plan is replaced by a specific starting strategy. Phase correction is when the ECU adjusts the timing to take into account the time taken for the HT pulse to reach the spark plugs. To ensure good driveability, the ECU can limit the variations between the two ignition systems to a maximum value, which varies according to engine speed and the basic injection period.

An anti-jerk function operates when the basic injection period is less than 2.5 ms and the engine speed is between 720 and 3200 rpm. This function operates to correct the programmed ignition timing in relation to the instantaneous engine speed and a set filtered speed; this is done to stabilise the engine rotational characteristics as much as possible.

To maintain constant-energy HT, the dwell period must increase in line with engine speed. To ensure that the ignition primary current reaches its maximum at the point of ignition, the ECU controls the dwell by use of another memory map, which takes battery voltage into account.

Fuel is collected from the tank by a pump either immersed in it or outside, but near the tank. The immersed type is quieter in operation, has better cooling and has no internal leaks. The fuel is directed forwards to the fuel rail or manifold, via a paper filter.

Fuel pressure is maintained at approximately 2.5 bar above manifold pressure by a regulator mounted on the fuel rail. Excess fuel is returned to the tank. The fuel is usually picked up via a swirl pot in the tank to prevent aeration of the fuel. Each of the four inlet manifold tracts has its own injector.

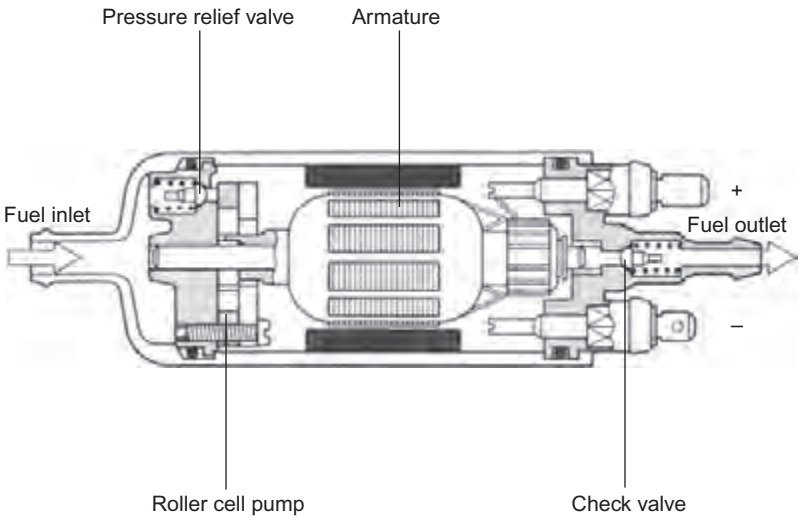


Figure 6.59 Roller cell pump

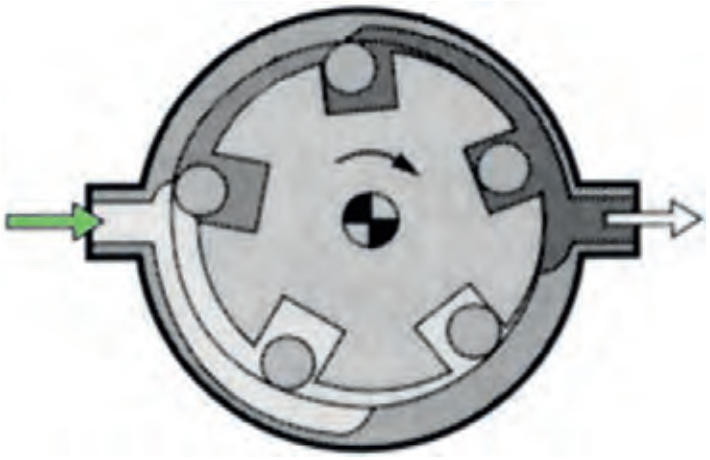


Figure 6.60 Roller cell pump (1)

Most fuel pumps on manifold injection systems are similar to Figure 6.59 and the pump operates as shown in Figures 6.60 and 6.61.

The fuel enters the pump housing where it is pressurised by rotation of the pump and the reduction of the volume in the roller chambers. This pressure opens a residual valve and fuel passes to the f lter. When the pump stops, pressure is maintained by this valve, which prevents the fuel returning. If due to a faulty regulator or a blockage in the line, fuel pressure rises above 7 bar, an overpressure valve will open releasing fuel back to the tank.

The fuel f lter is placed between the fuel pump and the fuel rail. It is f tted one way only to ensure the outlet screen traps any paper particles from the f lter element. The f lter will stop contamination down to between 8 and 10 µm.

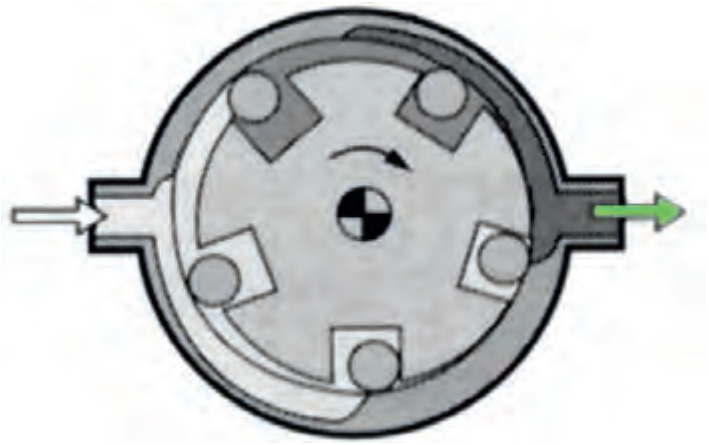


Figure 6.61 Roller cell pump (2)

Replacement varies between manufacturers, but 80 000 km (50 000 miles) is often recommended.

The fuel rail, in addition to providing a uniform supply to the injectors, acts as an accumulator. Depending on the size of the fuel rail, some systems also use an extra accumulator. The volume of the fuel rail is large enough to act as a pressure f uctuation damper, ensuring that all injectors are supplied with fuel at a constant pressure.

Key fact

The fuel rail, in addition to providing a uniform supply to the injectors, acts as an accumulator

Multipoint systems use one injector for each cylinder although very high-performance vehicles may use two. The injectors are connected to the fuel rail by a rubber seal. The injector is an electrically operated valve manufactured to a very high precision. The injector is composed of a body and needle attached to a magnetic core. When the winding in the injector housing is energised, the core or armature is attracted and the valve opens compressing a return spring. The fuel is delivered in a f ne spray to wait behind the closed inlet valve until the induction stroke begins. Provided the pressure across the injector remains constant, the quantity of fuel admitted is related to the open period, which, in turn, is determined by the time the electromagnetic circuit is energised.

The purpose of the fuel pressure regulator is to maintain differential pressure across the injectors at a predetermined constant. This means the regulator must adjust the fuel pressure in response to changes in manifold pressure. It is made of two compressed cases containing a diaphragm, spring and a valve.

Key fact

Multipoint manifold injection differential pressure is usually maintained at approximately 2.5ar – but always check data.

The calibration of the regulator valve is determined by the spring tension. Changes in manifold pressure vary the basic setting. When the fuel pressure is suff cient to move the diaphragm, the valve opens and allows the fuel to return to the tank. The decrease in pressure in the manifold, also acting on the diaphragm at say idle speed, will allow the valve to open more easily, hence maintaining a constant differential pressure between the fuel rail and the inlet manifold. This is a constant across the injectors, and hence the quantity of fuel injected is determined only by the open time of the injectors. The differential pressure is maintained at approximately 2.5 bar.

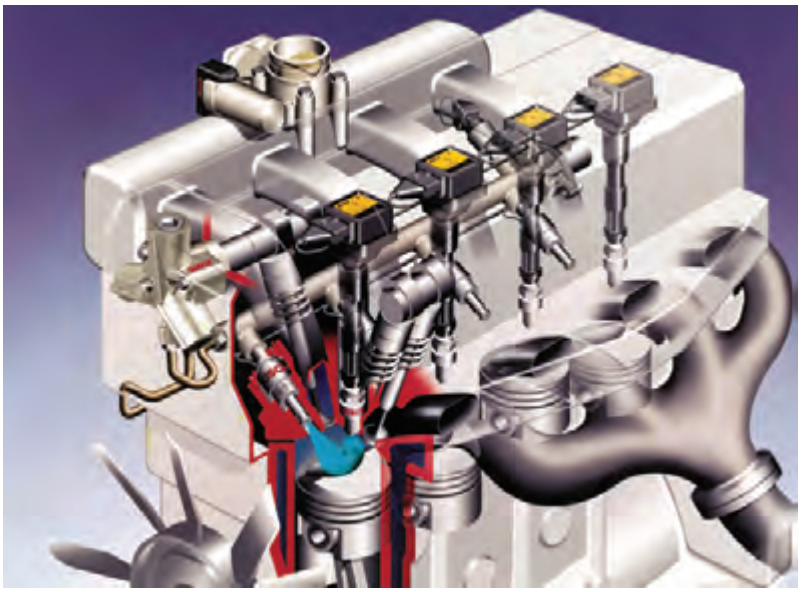


Figure 6.62 Gasoline direct injection (GDI)

The air supply circuit will vary considerably between manufacturers, but an individual manifold from a collector housing, into which the air is fed via a simple butterfly, supplies essentially each cylinder. The air is supplied from a suitable filter. A supplementary air circuit is utilised during the warm-up period after a cold start and to control idle speed.

Key fact

Gasoline direct injection (GDI) systems use a high-pressure pump to create a regulated pressure of up to 120 bar.

6.15.4 Gasoline direct injection

High-pressure injection systems for petrol/gasoline engines are based on a pressure reservoir and a fuel rail, which a high-pressure pump charges to a regulated pressure of up to 120 bar. The fuel can therefore be injected directly into the combustion chamber via electromagnetic injectors.

Definition

Homogeneous: A substance that is uniform in composition.

Heterogeneous: A substance that is random and non-uniform in composition.

The air mass drawn in can be adjusted through the electronically controlled throttle valve and is measured with the help of an air mass meter. For mixture control, a wide-band oxygen sensor is used in the exhaust, before the catalytic converters. This sensor can measure a range between a lambda value of 0.8 and infinity. The engine electronic control unit regulates the operating modes of the engine with gasoline direct injection (GDI) in three ways:

- stratified charge operation – with lambda values greater than 1;
- homogeneous operation – at lambda = 1;
- rich homogeneous operation – with lambda = 0.8.

Definition

Stratified charge: Fuel/air mixture is in layers.

Compared to the traditional manifold injection system, the Bosch DI-Motronic must inject the entire fuel amount in full-load operation in a quarter of the time. The available time is significantly shorter during stratified charge operation in part-load. Especially at idle, injection times of less than 0.5 ms are required due to the lower fuel consumption. This is only one-fifth of the available time for manifold injection (Figure 6.62).

The fuel must be atomised very finely in order to create an optimal mixture in the brief moment between injection and ignition (Figure 6.63). The fuel droplets for



Figure 6.63 Atomization

direct injection are on average smaller than 20 µm. This is only one-f fth of the droplet size reached with the traditional manifold injection and one-third of the diameter of a single human hair. This improves eff ciency considerably.

Direct injection engines operate according to the stratif ed charge concept in the part-load range and function with high excess air. In return, very low fuel consumption is achieved.

The engine operates with an almost completely opened throttle valve, which avoids additional alternating charge losses. With stratif ed charge operation, the lambda value in the combustion chamber is between approximately 1.5 and 3. In the part-load range, GDI achieves the greatest fuel savings with up to 40% at idle compared to conventional petrol injection processes. With increasing engine load, and therefore increasing injection quantities, the stratif ed charge cloud becomes even richer and emission characteristics become worse.

Because soot may form under these conditions, the DI-Motronic engine control converts to a homogeneous cylinder charge at a pre-def ned engine load. The system injects very early during the intake process in order to achieve a good mixture of fuel and air at a ratio of lambda = 1. As is the case for conventional manifold injection systems, the amount of air drawn in for all operating modes is adjusted through the throttle valve according to the desired torque specif ed by the driver.

Diagnosing faults with a GDI system is little different from the manifold injection types. Extra care is needed because of the higher fuel pressures of course. Injector waveforms can be checked as can those associated with the other sensors and actuators.

Key fact

The fuel droplets for direct injection are on average smaller than 20 µm.

6.16 Diagnostics – combined ignition and fuel systems

6.16.1 Testing procedure

The following procedure is very generic but with a little adaptation can be applied to any system. Refer to manufacturer's recommendations if in any doubt (Figure 6.64).

Safety f rst

Warning: Caution/Achtung/Attention – Burning fuel and high voltages can seriously damage your health.

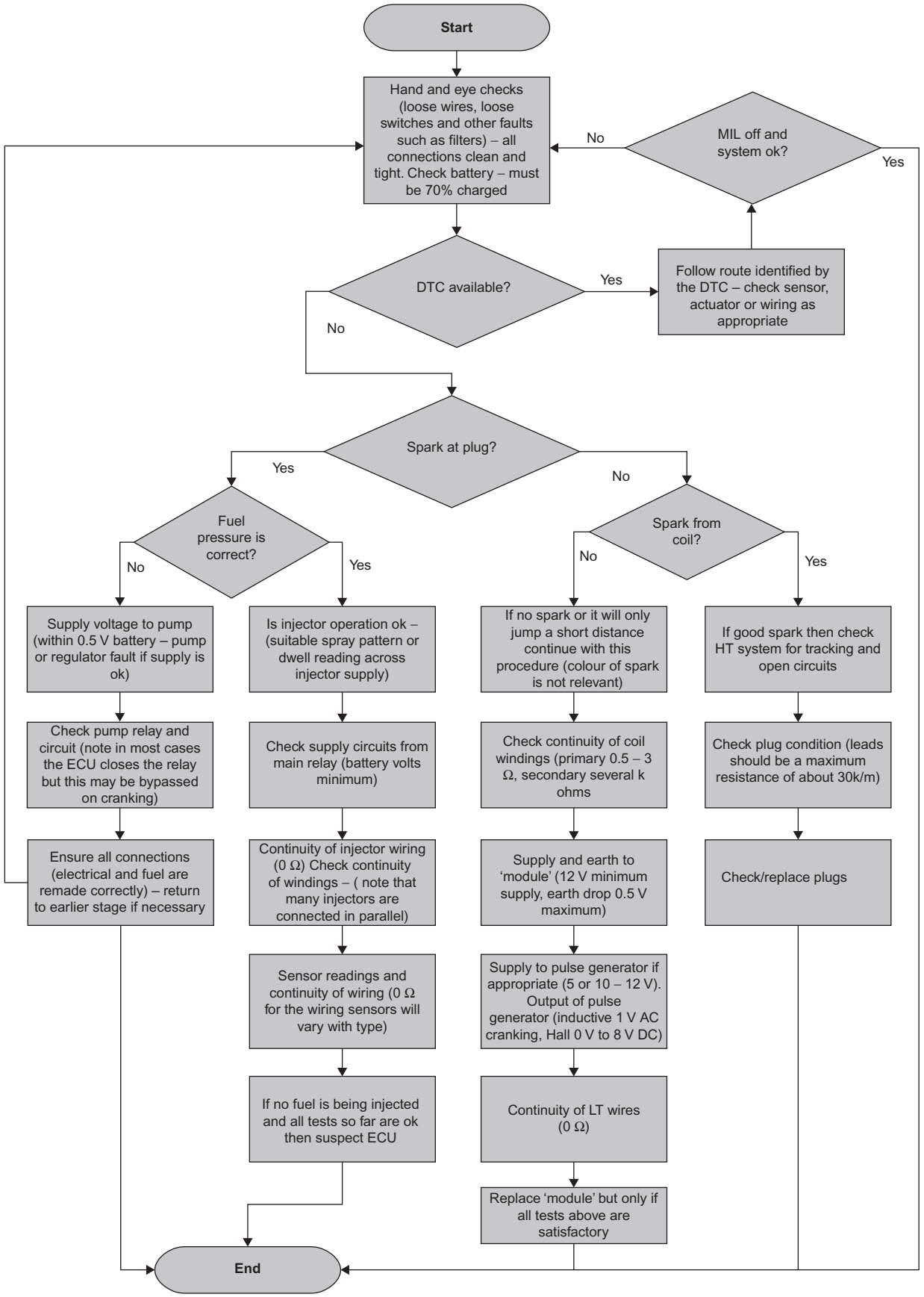


Figure 6.64 Engine management faultfinding chart

6.16.2 Combined ignition and fuel control fault diagnosis table

Symptom	Possible fault
Engine will not start	Engine and battery earth connections Fuel filter and fuel pump Air intake system for leaks Fuses/fuel pump/system relays Fuel injection system wiring and connections Coolant temperature sensor Auxiliary air valve/idle speed control valve Fuel pressure regulator and delivery rate ECU and connector Limp home function – if fitted
Engine difficult to start when cold	Engine and battery earth connections Fuel injection system wiring and connections Fuses/fuel pump/system relays Fuel filter and fuel pump Air intake system for leaks Coolant temperature sensor Auxiliary air valve/idle speed control valve Fuel pressure regulator and delivery rate ECU and connector Limp home function – if fitted
Engine difficult to start when warm	Engine and battery earth connections Fuses/fuel pump/system relays Fuel filter and fuel pump Air intake system for leaks Coolant temperature sensor Fuel injection system wiring and connections Air mass meter Fuel pressure regulator and delivery rate Air sensor filter ECU and connector Knock control – if fitted
Engine starts then stops	Engine and battery earth connections Fuel filter and fuel pump Air intake system for leaks Fuses/fuel pump/system relays Idle speed and CO content Throttle potentiometer Coolant temperature sensor Fuel injection system wiring and connections ECU and connector Limp home function – if fitted
Erratic idling speed	Engine and battery earth connections Air intake system for leaks Auxiliary air valve/idle speed control valve Idle speed and CO content Fuel injection system wiring and connections Coolant temperature sensor Knock control – if fitted Air mass meter Fuel pressure regulator and delivery rate

(*Continued*)

Symptom	Possible fault
	ECU and connector Limp home function – if fitted
Incorrect idle speed	Air intake system for leaks Vacuum hoses for leaks Auxiliary air valve/idle speed control valve Idle speed and CO content Coolant temperature sensor
Misfire at idle speed	Engine and battery earth connections Air intake system for leaks Fuel injection system wiring and connections Coolant temperature sensor Fuel pressure regulator and delivery rate Air mass meter Fuses/fuel pump/system relays
Misfire at constant speed	Airflow sensor
Hesitation when accelerating	Engine and battery earth connections Air intake system for leaks Fuel injection system wiring and connections Vacuum hoses for leaks Coolant temperature sensor Fuel pressure regulator and delivery rate Air mass meter ECU and connector Limp home function – if fitted
Hesitation at constant speed	Engine and battery earth connections Throttle linkage Vacuum hoses for leaks Auxiliary air valve/idle speed control valve Fuel lines for blockage Fuel filter and fuel pump Injector valves ECU and connector Limp home function – if fitted
Hesitation on overrun	Air intake system for leaks Fuel injection system wiring and connections Coolant temperature sensor Throttle potentiometer Fuses/fuel pump/system relays Air sensor filter Injector valves Air mass meter
Knock during acceleration	Knock control – if fitted Fuel injection system wiring and connections Air mass meter ECU and connector
Poor engine response	Engine and battery earth connections Air intake system for leaks Fuel injection system wiring and connections Throttle linkage Coolant temperature sensor Fuel pressure regulator and delivery rate

(*Continued*)

Symptom	Possible fault
	Air mass meter ECU and connector Limp home function – if fitted
Excessive fuel consumption	Engine and battery earth connections Idle speed and CO content Throttle potentiometer Throttle valve/housing/sticking/initial position Fuel pressure regulator and delivery rate Coolant temperature sensor Air mass meter Limp home function – if fitted
CO level too high	Limp home function – if fitted ECU and connector Emission control and EGR valve – if fitted Fuel injection system wiring and connections Air intake system for leaks Coolant temperature sensor Fuel pressure regulator and delivery rate
CO level too low	Engine and battery earth connections Air intake system for leaks Idle speed and CO content Coolant temperature sensor Fuel injection system wiring and connections Injector valves ECU and connector Limp home function – if fitted Air mass meter Fuel pressure regulator and delivery rate
Poor performance	Engine and battery earth connections Air intake system for leaks Throttle valve/housing/sticking/initial position Fuel injection system wiring and connections Coolant temperature sensor Fuel pressure regulator/fuel pressure and delivery rate Air mass meter ECU and connector Limp home function – if fitted

6.16.3 Fuel pump testing

Typical high-pressure fuel pump characteristics are as follows (Figure 6.65):

- **delivery** – 120 L/h (1 L in 30 s) at 3 bar;
- **resistance** – 0.8 Ω (static);
- **voltage** – 12 V;
- **current** – 10.5 A.

An ideal test for a fuel pump is its delivery. Using a suitable measuring receptacle, bypass the pump relay and check the quantity of fuel delivered in a set time (refer to manufacturer's specifications). A reduced amount would indicate either a fuel blockage, a reduced electrical supply to the pump or an inefficient pump.



Figure 6.65 Airflow meter under test

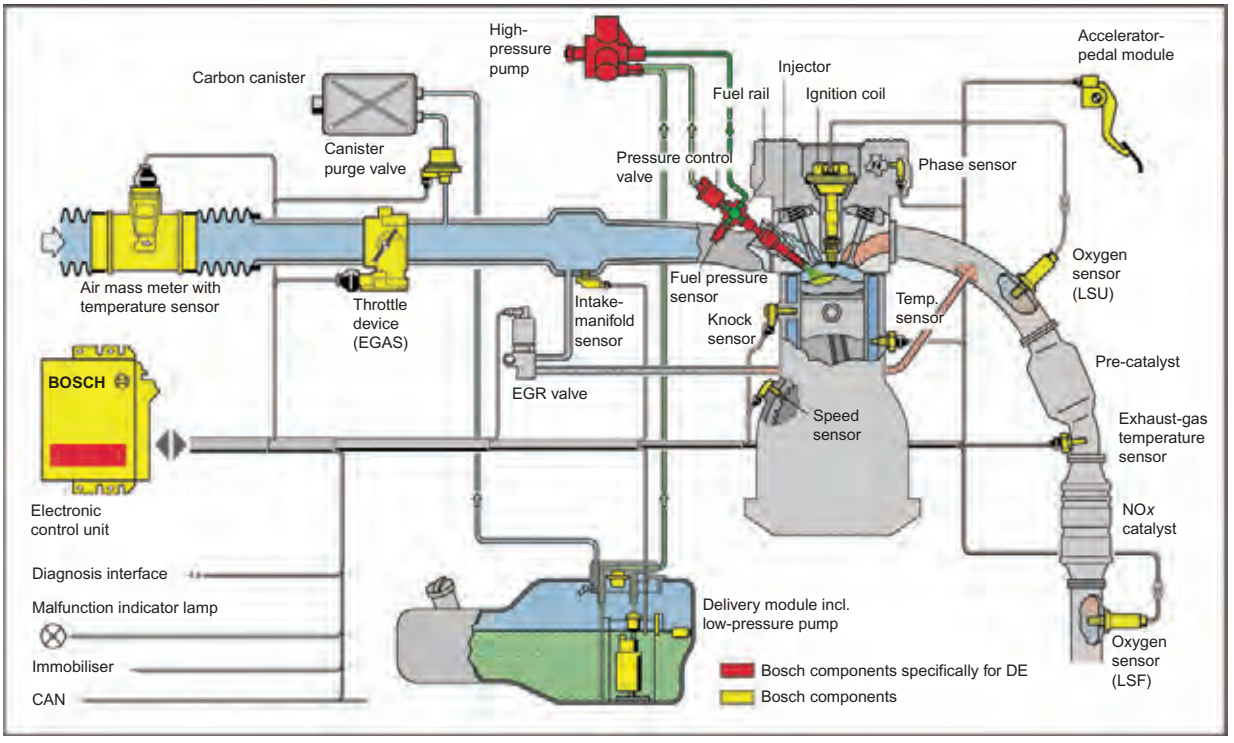


Figure 6.66 Motronic M5 with OBD2 (Source: Bosch Media)

6.16.4 Injector testing

Injectors typically have the characteristics as listed:

- supply voltage – 12 V;
- resistance – 16 Ω;
- static output – 150 cc/min at 3 bar.

As always, check with actual data before carrying out any tests (Figure 6.66).

Resistance checks (with the supply disconnected) are an ideal start to testing injectors. Further tests with the fuel pressurised by the pump and each injector in turn held in a suitable receptacle, include the following:

- **spray pattern** – usually a nice cone shape with good atomisation;
- **delivery** – set quantity over a set time;
- **leakage** – any linkage of more than two drops a minute for standard non-direct injectors is considered excessive (zero is desirable).

6.17 Engine management and faultf nding information

6.17.1 Diagnosis charts

'Autodata' supply diagnosis charts specif c to particular management systems are shown below. Note that some boxes refer you to a further publication (Figure 6.67).

6.17.2 Circuit diagrams

Circuit diagrams can be printed out from some CD-based data sources (Figure 6.68).

6.17.3 Component testing data

Figure 6.69 is an example printout of the type of component testing data that is available.

6.18 Air supply and exhaust systems

6.18.1 Exhaust system

A vehicle exhaust system directs combustion products away from the passenger compartment, reduces combustion noise and, on most modern vehicles, reduces harmful pollutants in the exhaust stream. The main parts of the system are the exhaust manifold, the silencer or muff er, the pipes connecting them and a catalytic converter.

Most exhaust systems are made from mild steel, but some are made from stainless steel which lasts much longer. The system is suspended under the vehicle on rubber mountings. These allow movement because the engine is also rubber mounted, and they also reduce vibration noise.

An exhaust manifold links the engine exhaust ports to the down pipe and main system. It also reduces combustion noise and transfers heat downstream to allow the continued burning of hydrocarbons and carbon monoxide. The manifold is connected to the down pipe, which in turn can be connected to the catalytic converter. Most exhaust manifolds are made from cast iron, as this has the necessary strength and heat transfer properties.

The silencer's main function is to reduce engine noise to an acceptable level. Engine noise is a mixed-up collection of its f ring frequencies (the number of

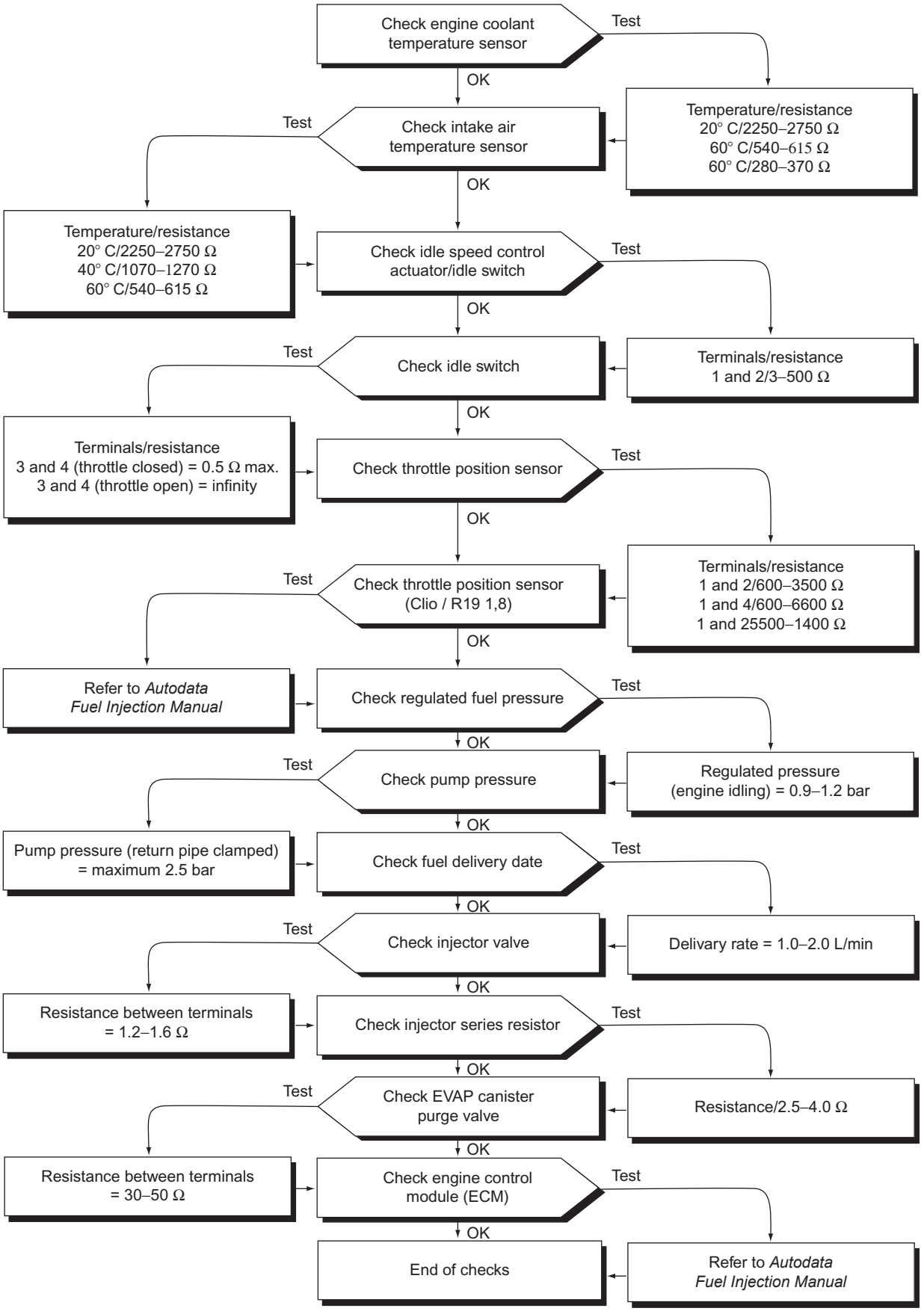


Figure 6.67 Faultf ndingchart

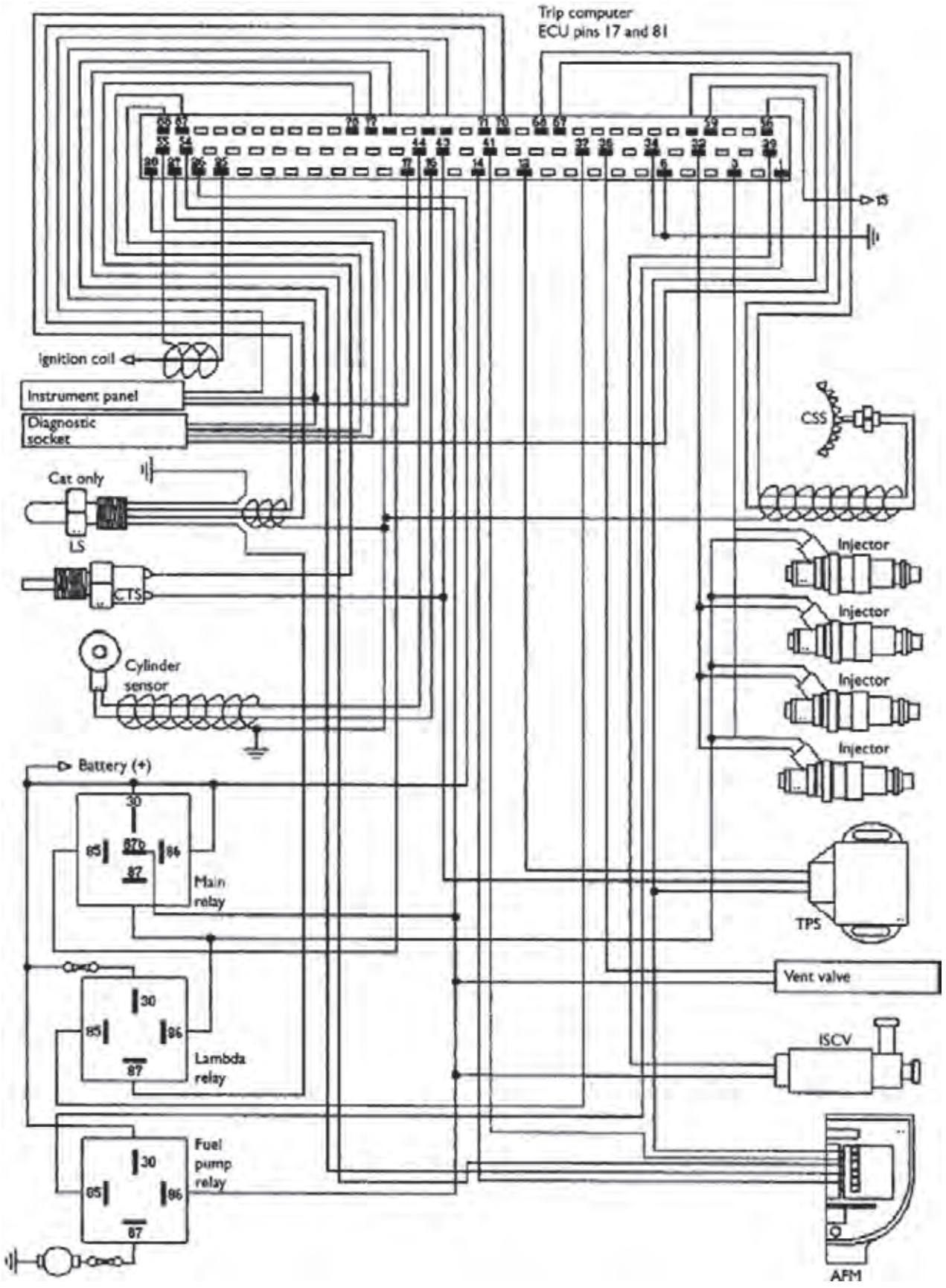


Figure 6.68 Engine management circuit diagram

Mazda 626 2.0i GX 16 valve					
Fuel and ignition Diagnostics					
Air Mass Meter					
position	in the intake tubing				
condition					
ignition on / meter plug disconnected					
connection 5 / green / red v+					
	from	4.8	to	5.2	volts
connection 3 / black / orange v–					
condition					
ignition on /meter plug connected					
connection 2 / brown / blue v+					
	from	4	to	6	volts
connection 3 / black / orange v–					
condition					
ignition on /meter plug connected / engine off					
connection 1 / white / blue v+					
	from	0	to	0.3	volts
connection 3 / black / orange v–					
condition					
meter plug connected / engine running at idle					
connection 1 / white / blue v+					
	from	0.4	to	1	volts
connection 3 / black / orange v–					

Figure 6.69 Testing data

times per second each cylinder f res). These range from approximately 100 to 400 Hz (cycles/s). A silencer reduces noise in two main ways:

- interior chambers using baff es, which are tuned to set up cancelling vibrations;
- absorptive surfaces function like sound-deadening wall and ceiling panels to absorb noise.

When the exhaust gases f nally leave the exhaust system, their temperature, pressure and noise have been reduced considerably. The overall length of an exhaust system including the silencers can affect the smooth f ow of gases. For this reason, do not alter the length or change the layout of an exhaust system (Figure 6.70).

6.18.2 Catalytic converters

Key fact

Stringent regulations in most parts of the world have made the use of a catalytic converter essential.

Stringent regulations in most parts of the world have made the use of a catalytic converter essential. The TWC is used to great effect by most manufacturers. It is in effect a very simple device; it looks similar to a standard exhaust silencer box. Note that in order for the ‘cat’ to operate correctly, the engine must be always well tuned. This is to ensure that the right ‘ingredients’ are available for the catalyst to perform its function. A catalytic converter works by converting the dangerous exhaust gases into gases which are non-toxic (Figure 6.71).

The core has traditionally been made from ceramic of magnesium aluminium silicate. Owing to the several thousand very small channels, this provides a large surface area. It is coated with a wash coat of aluminium oxide, which again

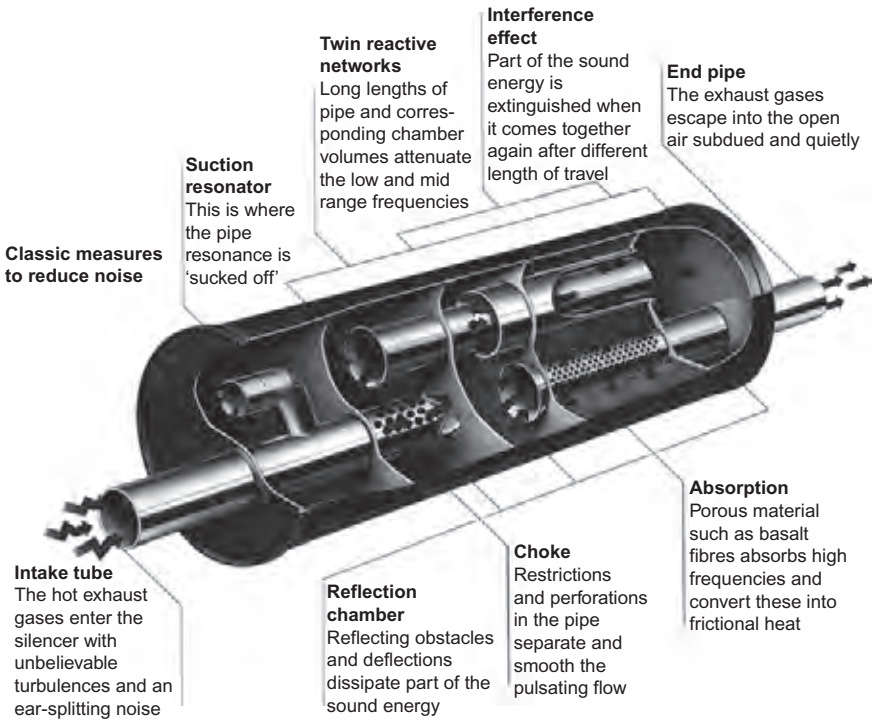


Figure 6.70 Exhaust noise reduction methods

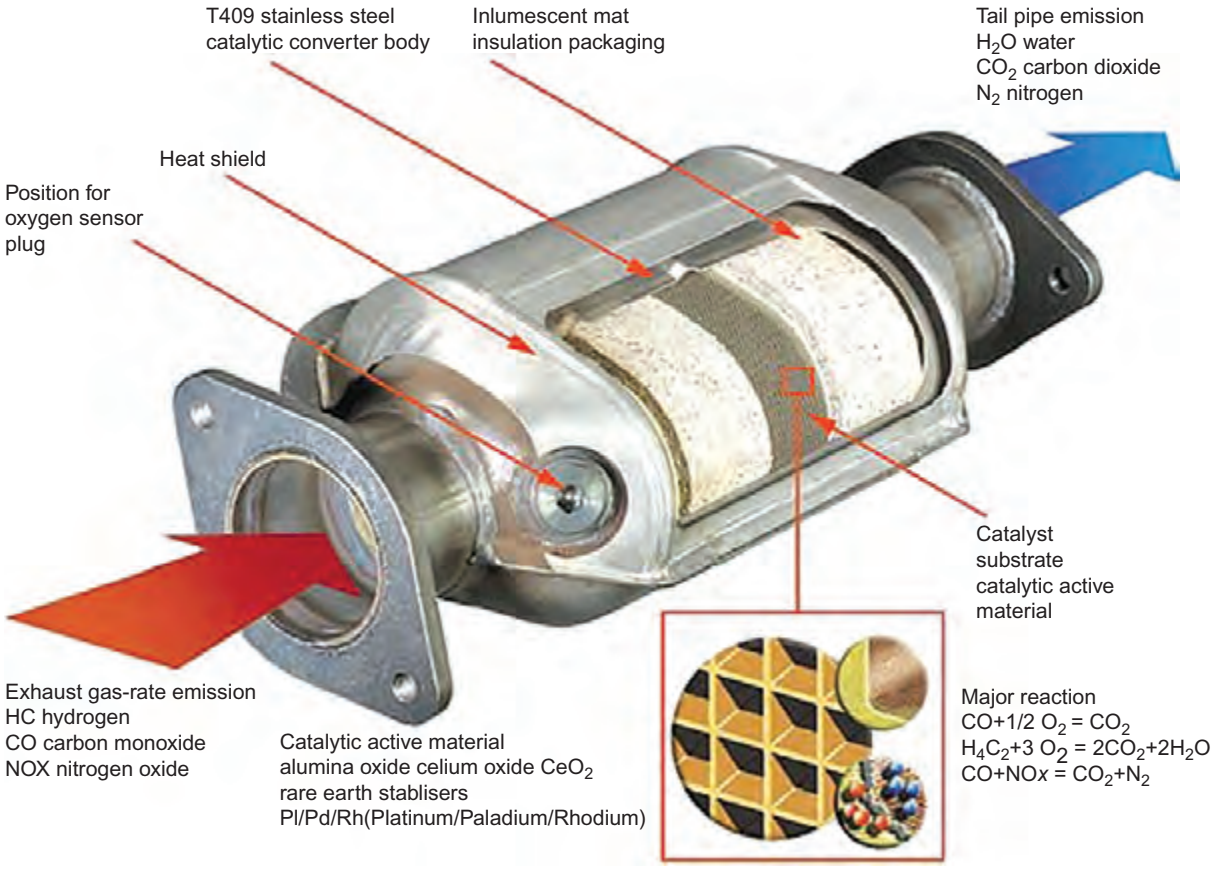


Figure 6.71 Catalytic converter components and operation

increases its effective surface area by about several thousand times. 'Noble' metals are used for the catalysts. Platinum helps to burn off the hydrocarbons (HC) and carbon monoxide (CO), and rhodium helps in the reduction of nitrogen oxides (NO_x). The whole three-way catalytic converter contains only about 3–4 g of these precious metals. Some converters now use metal cores (substrates).

The engine can damage a catalytic converter in one of two ways:

- f rst by the use of leaded fuel which can cause lead compounds to be deposited on the active surfaces;
- second by engine misf re which can cause the catalytic converter to overheat due to burning fuel inside the unit.

Some manufacturers use a system on some vehicles where a sensor checks the output of the ignition HT system and, if the spark is not present, will not allow fuel to be injected. Misf re detection is also part of current on-board diagnostic (OBD) legislation in some countries and future legislation in others.

6.18.3 Air supply system

There are three purposes of the complete air supply system:

1. clean the air;
2. control air temperature;
3. reduce noise.

A f lter does the air cleaning and drawing air from around the exhaust manifold helps to control air temperature. When large quantities of air are drawn into the engine, it causes the air to vibrate and this makes it noisy. In the same way as with the exhaust system, baff es are used to stop resonance. Resonance means that when vibrations reach a natural level they tend to increase and keep going. A good example of how much noise is reduced by the air intake system is to compare the noise when an engine is run with the air f lter removed.

Two types of air f lter are in use, the f rst of these being by far the most popular:

- paper element;
- oil bath and mesh.

Key fact

A paper air lter element is made of resin-impregnated paper.

The paper element is made of resin-impregnated paper. Air f lters using this type of replaceable element are used for both car and commercial vehicles. They provide a very high f ltering eff ciency and reasonable service life. They can be mounted in any position available under the bonnet. Service intervals vary, so check recommendations.

The oil bath and mesh type of air cleaner was widely used on non-turbo charged commercial vehicles. However, it is not very practical for modern low styled bonnets. Because it can be cleaned and fresh oil added, an oil bath air cleaner might still be used for vehicles operating in dusty conditions.

Air temperature control is used to help the vehicle conform to emission control regulations and for good driveability when the engine is cold. Good vaporisation of the fuel is the key. An automatic control is often f tted to make sure that the air intake temperature is always correct. The air cleaner has two intake pipes, one for cold air and the other for hot air from the exhaust manifold or hot box. The proportion of hot and cold air is controlled by a f ap, which is moved by a diaphragm acted on by low pressure from the inlet manifold. The f ap rests in the hot air pick-up position.

A thermo-valve in the air stream senses the temperature of the air going into the engine. When a temperature of approximately 25 °C is reached, the valve opens. This removes the connection to the manifold, which in turn increases the pressure acting on the diaphragm. The flap is now caused to move and the pick-up is now from the cool air position. The flap is constantly moving, ensuring that the temperature of air entering the engine remains constant. Picking up hot air when the engine is very cold can also help to prevent icing.

6.19 Diagnostics – exhaust and air supply

6.19.1 Systematic testing

If the reported fault is a noisy exhaust, proceed as follows:

1. Check if the noise is due to the exhaust knocking or blowing.
2. Examine the vehicle on the lift.
3. Check whether further tests are required or the fault is obvious?
4. Cover the end of the exhaust pipe with a rag for a second or two to highlight where the exhaust may be blowing.
5. Renew the exhaust section or complete system as appropriate.
6. Run and test for leaks and knocking.

6.19.2 Test results

Some of the information you may have to get from other sources such as data books or a workshop manual is listed in Table 6.6.

6.19.3 Exhaust and air supply fault diagnosis table 1

Symptom	Possible faults	Suggested action
Exhaust noise	Hole in pipe, box or at joints	Renew as appropriate
Knocking noise	Exhaust incorrectly positioned	Reposition
	Broken mountings	Renew
Rich mixture/smoke	Blocked air filter	Replace
Noisy air intake	Intake trunking or filter box leaking or loose	Repair or secure as required
Poor cold driveability	Hot air pick-up not operating	Check pipe connections to inlet manifold for leaks. Renew temperature valve or actuator

Table 6.6 Tests and information required

Test carried out	Information required
Air filter condition	Clearly a physical examination but note the required service intervals
Exhaust noise	An idea of the normal noise level – note that 'big-bore' exhausts will make more noise than the 'correct' type

6.19.4 Exhaust fault diagnosis table 2

Symptom	Possible cause
Excessive noise	Leaking exhaust system or manifold joints Hole in exhaust system
Excessive fumes in car	Leaking exhaust system or manifold joints
Rattling noise	Incorrect fitting of exhaust system Broken exhaust mountings Engine mountings worn

6.20 Cooling

6.20.1 Air-cooled system

Air-cooled engines with multicylinders, especially under a bonnet, must have some form of fan cooling and ducting. This is to make sure that all cylinders are cooled evenly. The cylinders and cylinder heads are finned. Hotter areas, such as near the exhaust ports on the cylinders, have bigger fins.

Fan-blown air is directed by a metal cowling, so it stays close to the finned areas. A thermostatically controlled flap will control airflow. When the engine is warming up, the flap will be closed to restrict the movement of air. When the engine reaches its operating temperature, the flap opens and allows the air to flow over the engine. The cooling fan is a large device and is driven from the engine by a belt. This belt must not be allowed to slip or break, because serious damage will occur.

Car heating is not easy to arrange with an air-cooled engine. Some vehicles use a heat exchanger around the exhaust pipe. Air is passed through this device where it is warmed. It can then be used for demisting and heating with the aid of an electric motor and fan.

6.20.2 Water-cooled system

The main parts of a water-cooled system are as follows:

- water jacket;
- water pump;
- thermostat;
- radiator;
- cooling fan.

Water-cooled engines work on the principle of surrounding the hot areas inside the engine with a water jacket. The water takes on heat from the engine and, as it circulates through the radiator, gives it off to atmosphere. The heat concentration around the top of the engine means a water pump is needed to ensure proper circulation.

The water pump circulates water through the radiator and around the engine when the thermostat is open. Water circulates only round the engine when the thermostat is closed and not through the radiator. Forcing water around the engine prevents vapour pockets forming in very hot areas. This circulation is assisted by the thermo-siphon action. The thermo-siphon action causes the water to circulate because as the water is heated it rises and moves to the top of

the radiator. This pushes down on the colder water underneath which moves into the engine. This water is heated, rises and so on.

Coolant from the engine water jacket passes through a hose to the radiator at the top. It then passes through thin pipes called the radiator matrix to the lower tank and then back to the lower part of the engine.

Many water passages between the top and bottom tanks of the radiator are used to increase the surface area. Fins further increase the surface area to make the radiator even more eff cient. A cooling fan assists airf ow. The heat from the coolant passes to the pipes and f ns and then to the air as it is blown by a fan over the f ns.

Many modern radiators are made from aluminium pipes and f ns with plastic tanks top and bottom (down-f ow), or at each end (cross-f ow). The cross-f ow radiators with tanks at each end are becoming the most popular. The more traditional method was to use copper and brass.

A thermostat is a temperature-controlled valve. Its purpose is to allow coolant to heat up more quickly and then be kept at a constant temperature. The total coolant volume in an engine takes time to heat up. Modern engines run more eff ciently when at the correct operating temperature. The action of the thermostat is such as to prevent water circulation from the engine to the radiator, until a set temperature is reached. When the valve opens, there is a full circuit for the coolant and a good cooling action occurs because of full f ow through the radiator. The constant action of the thermostat ensures that the engine temperature remains at a constant level. The thermostat used by almost all modern engines is a wax capsule type. If the thermostat is faulty, ensure that the correct type for the engine is f tted, as some work at different temperatures.

The water pump is driven by a V-belt or multi-V-belt from the crankshaft pulley or by the cam belt. The pump is a simple impeller type and is usually f tted at the front of the engine (where the pulleys are). It assists with the thermo-siphon action of the cooling system, forcing water around the engine block and radiator.

The engine fan, which maintains the f ow of air through the radiator, is mounted on the water-pump pulley on older systems. Most cooling fans now are electric. These are more eff cient because they only work when needed. The forward motion of the car also helps the air movement through the radiator.

Key fact

Most modern radiators are made from aluminium pipes and fins with plastic tanks.

6.20.3 Sealed and semi-sealed systems

Cooling systems on most vehicles today are sealed or semi-sealed. This allows them to operate at pressures as much as 100 N/m^2 (100 Pa) over atmospheric pressure, raising the boiling point of the coolant to as much as 126.6 °C (remember water boils at 100° C at atmospheric pressure). The system can therefore operate at a higher temperature and with greater eff ciency.

The pressure build-up is made possible by the radiator pressure cap. The cap contains a pressure valve which opens at a set pressure, and a vacuum valve which opens at a set vacuum. On a semi-sealed system, air is pushed out to atmosphere through the pressure valve as the coolant expands. Air is then drawn back into the radiator through the vacuum valve as the coolant cools and contracts. A sealed system has an expansion tank into which coolant is forced as it expands, and when the engine cools, coolant can f ow from the tank back into the cooling system. Figure 6.72 shows a semi-sealed type cooling system.

Correct levels in the expansion tank or in an unsealed radiator are very important. If too much coolant is used, it will be expelled on to the f oor when the engine

Safety f rst

Warning: If a pressure cap is removed from a hot system, hot water under pressure will boil the instant pressure is released. This can be very dangerous.

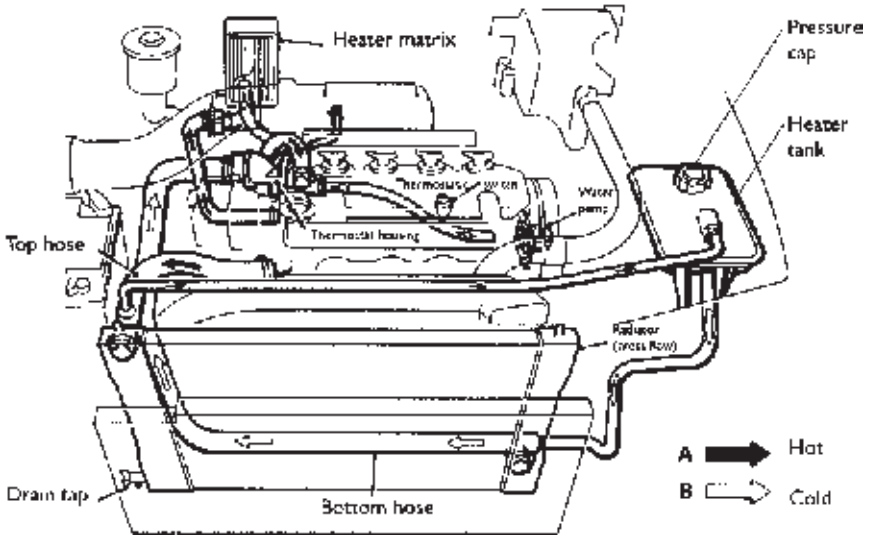


Figure 6.72 Semi-sealed cooling system

gets hot. If not enough is used, then the level could become low and overheating could take place.

Heat from the engine can be used to increase the temperature of the car interior. This is achieved by use of a heat exchanger, often called the heater matrix. Owing to the action of the thermostat in the engine cooling system, the water temperature remains nearly constant. The air being passed over the heater matrix is therefore heated to a set level.

A source of hot air is now available for heating the vehicle interior. Some form of control is required over how much heat is required. The method used on most modern vehicles is blending. This is a control f ap that determines how much of the air being passed into the vehicle is directed over the heater matrix. Some systems use a valve to control the hot coolant f owing to the heater matrix.

By a suitable arrangement of f aps, it is possible to direct air of the chosen temperature to selected areas of the vehicle interior. In general, basic systems allow the warm air to be adjusted between the inside of the windscreen and the driver and passenger footwells. Fresh cool air outlets with directional nozzles are also f tted.

One f nal facility, which is available on many vehicles, is the choice between fresh or recirculated air. The primary reason for this is to decrease the time taken to demist or defrost the vehicle windows and simply to heat the car interior more quickly, and to a higher temperature. The other reason is that for example, in heavy congested traff c, the outside air may not be very clean.

6.21 Diagnostics – cooling

6.21.1 Systematic testing

If the reported fault is loss of coolant, proceed as follows:

1 Check coolant level and discuss with customer how much is being lost.
2 Run the engine to see if it is overheating.

3 If the engine is not overheating, a leak would seem to be most likely.
4 Pressure-test the cooling system and check for leaks from hoses, gaskets and the radiator.
5 Renew a gasket or the radiator, clips or hoses as required. Top up the coolant and check antifreeze content.
6 Road-test the vehicle to conf rm the fault is cured and that no other problems have occurred.

6.21.2 Test equipment

Note: You should always refer to the manufacturer's instructions appropriate to the equipment you are using.

Cooling system pressure tester

This is a pump with a pressure gauge built in, together with suitable adapters for f tting to the header tank or radiator f ller. The system can then be pressurized to check for leaks. The pressure can be looked up or it is often stamped on the f ller cap. A good way of doing this test is to pressurise the system when cold and then start the engine and allow it to warm up. You can be looking for leaks, but beware of rotating components.

Antifreeze tester

This piece of equipment is a hydrometer used to measure the relative density of the coolant. The relative density of coolant varies with the amount of antifreeze. A table can be used to determine how much more antifreeze should be added to give the required protection.

Temperature meter/thermometer

Sometimes the dashboard temperature gauge reading too high can create the symptoms of an overheating problem. A suitable meter or thermometer can be used to check the temperature. Note, though, that normal operating temperature is often well above 90 °C (hot enough to burn badly) (Figure 6.73).



Figure 6.73 Cooling system testing kit (Source: Sykes Pickavant)

6.21.3 Test results

Some of the information you may have to get from other sources such as data books or a workshop manual is listed in Table 6.7.

Table 6.7 Tests and information required

Test carried out	Information required
Leakage test	System pressure. Printed on the cap or from data books. Approximately 1bar is normal
Antifreeze content	Cooling system capacity and required percentage of antifreeze. If the system holds 1.6 then for a 50% antifreeze content you will need to add 1.3 of antifreeze. Do not forget you will need to drain out 1.3 water to make room for the antifreeze
Operating temperature	This is about the same as the thermostat opening temperature. 88–92°C is a typical range

6.21.4 Cooling fault diagnosis table 1

Symptom	Possible faults	Suggested action
Overheating	Lack of coolant Thermostat stuck closed Electric cooling fan not operating Blocked radiator Water pump/fan belt slipping	Top up but then check for leaks Renew Check operation of thermal switch Renew Check, adjust/renew
Loss of coolant	Leaks	Pressure test when cold and hot, look for leaks and repair as required
Engine does not reach normal temperature or it takes a long time	Thermostat stuck in the open position	Renew

6.21.5 Cooling fault diagnosis table 2

Symptom	Possible cause
Overheating	Low coolant level (maybe due to a leak) Thermostat stuck closed Radiator core blocked Cooling fan not operating Temperature gauge inaccurate Airlock in system (some systems have a complex bleeding procedure) Pressure cap faulty
Overcooling	Thermostat stuck open Temperature gauge inaccurate Cooling fan operating when not needed
External coolant leak	Loose or damaged hose Radiator leak Pressure cap seal faulty Water pump leak from seal or bearing Boiling due to overheating or faulty pressure cap Core plug leaking
Internal coolant leak	Cylinder head gasket leaking Cylinder head cracked
Corrosion	Incorrect coolant (antifreeze, etc.) Infrequent fushing
Freezing	Lack of antifreeze Incorrect antifreeze

6.22 Lubrication

6.22.1 Lubrication system

From the sump reservoir under the crankshaft, oil is drawn through a strainer into the pump. Oil pumps have an output of tens of litres per minute and operating

pressures of more than 5 bar at high speeds. A pressure relief valve limits the pressure of the lubrication system to between 2.5 and 4 bar. This control is needed because the pump would produce excessive pressure at high speeds. After leaving the pump, oil passes into a f lter and then into a main oil gallery in the engine block or crankcase.

Drillings connect the gallery to the crankshaft bearing housings and, when the engine is running, oil is forced under pressure between the rotating crank journals and the main bearings. The crankshaft is drilled so that the oil supply from the main bearings is also to the big-end bearing bases of the connecting rods.

The con rods are often drilled near the base so that a jet of oil sprays the cylinder walls and the underside of the pistons. In some cases, the con rod may be drilled along its entire length so that oil from the big-end bearing is taken directly to the gudgeon pin (small end). The surplus then splashes out to cool the underside of the piston and cylinder.

The camshaft operates at half crankshaft speed, but it still needs good lubrication because of the high-pressure loads on the cams. It is usual to supply pressurised oil to the camshaft bearings and splash or spray oil on the cam lobes. On overhead camshaft engines, two systems are used. In the simplest system, the rotating cam lobes dip into a trough of oil. Another method is to spray the cam lobes with oil. This is usually done by an oil pipe with small holes in it alongside the camshaft. The small holes in the side of the pipe aim a jet of oil at each rotating cam lobe. The surplus splashes over the valve assembly and then falls back into the sump.

On cars where a chain drives the cam, a small tapping from the main oil gallery sprays oil on the chain as it moves past or the chain may simply dip in the sump oil.

6.22.2 Oil f lters

Even new engines can contain very small particles of metal left over from the manufacturing process or grains of sand which have not been removed from the crankcase after casting. Old engines continually deposit tiny bits of metal worn from highly loaded components such as the piston rings. To prevent any of these lodging in bearings or blocking oil ways, the oil is f ltered.

The primary f lter is a wire mesh strainer that stops particles of dirt or swarf from entering the oil pump. This is normally on the end of the oil pick-up pipe. An extra f lter is also used that stops very f ne particles. The most common type has a folded, resin-impregnated paper element. Pumping oil through it removes all but smallest solids from the oil.

Most engines use a full-f ow system to f lter all the oil after it leaves the pump. The most popular method is to pump the oil into a canister containing a cylindrical f lter. From the inner walls of the canister, the oil f ows through the f lter and out from the centre to the main oil gallery. Full-f ow f ltration works well, provided the f lter is renewed at regular intervals. If it is left in service too long, it may become blocked. When this happens, the build-up of pressure inside the f lter forces open a spring-loaded relief valve in the housing and the oil bypasses the f lter. This valve prevents engine failure, but the engine will be lubricated with dirty oil until the f lter is renewed. This is better than no oil.

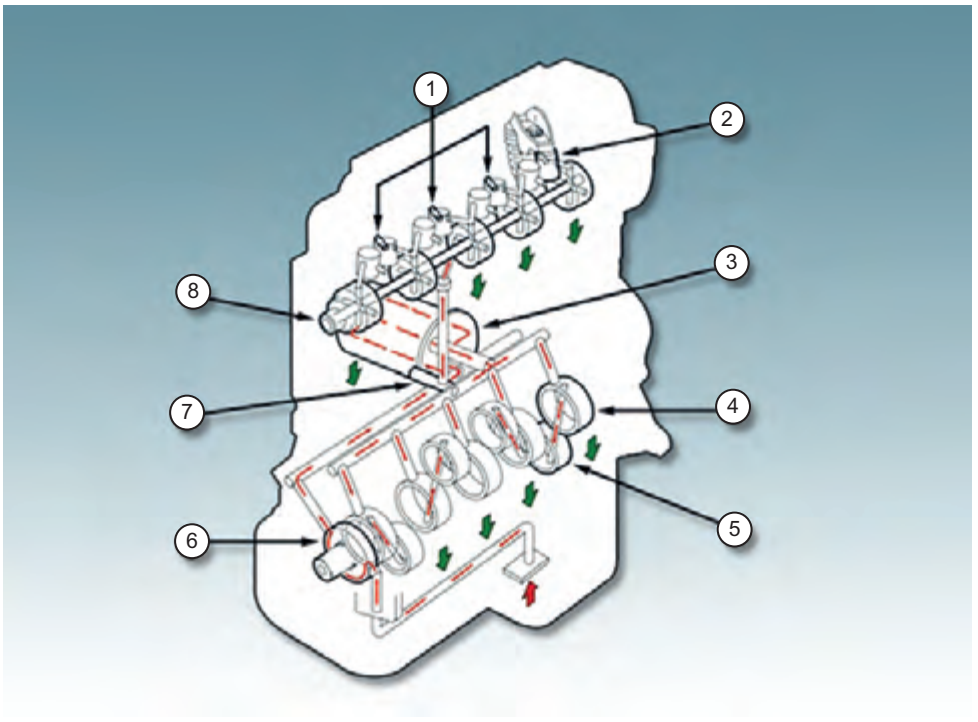


Figure 6.74 Oil flow: 1 – oil to rocker arms; 2 – hydraulic tappets; 3 – crank main bearings; 4 – big-end bearings; 5 – oil under pressure; 6 – crank driven oil pump; 7 – oil filter; 8 – camshaft

A bypass filtration system was used on older vehicles. This system filters only a proportion of the oil pump output. The remainder is fed directly to the oil gallery. At first view, this seems a strange idea, but all the oil does eventually get filtered. The smaller amount through the filter allows a higher degree of filtration (Figure 6.74).

6.22.3 Oil pumps

In its simplest form, an oil pump consists of two gear wheels meshed together in a tight space so that oil cannot escape past the sides. The engine drives one wheel. As the gears rotate in opposite directions, the gap between each tooth in each wheel traps a small quantity of oil from an inlet port. The trapped oil is carried round by each wheel towards an outlet port on the opposite side where it is forced out by the meshing teeth.

The principle of squeezing oil from an ever-decreasing space is also used in the rotor-type pump. An inner and outer rotor are mounted on different axes in the same cylinder. The inner rotor, which commonly has four lobes, is driven by the engine. It meshes with an outer rotor, which has five lobes. As they rotate, the spaces between them change size. The inlet port is at a point where the space between the rotor lobes is increasing. This draws the oil into the pump. The oil is then carried round the pump. As rotation continues, the space between the lobes gets smaller. This compresses the oil out of the outlet port.

Key fact

Oil pumps can produce more pressure than is required, so a pressure relief valve is used.

Oil pumps can produce more pressure than is required. A valve is used to limit this pressure to a set value. The pressure relief valve is a simple device, which in most cases works on the ball and spring principle. This means that when the pressure on the ball is greater than the spring, the ball moves. The pressure relief

valve is placed in the main gallery so that excess pressure is prevented. When the ball moves, oil is simply returned to the sump.

6.22.4 Crankcase ventilation engine breather systems

Breathing is very important; without being able to breathe, we would die. It is almost as important for an engine breathing system to work correctly. There are two main reasons for engine breathers:

1 Prevent pressure build-up inside the engine crankcase due to combustion gases blowing past the pistons. The build-up of pressure will blow gaskets and seals but also there is a high risk of explosion.
2 Prevent toxic emissions from the engine. Emission limits are now very strict, for good reason – our health.

Crankcase breathing or ventilation of the engine was first achieved by what is known as an open system, but this has now been completely replaced by the closed system. The gases escaping from an engine with open crankcase ventilation as described above are very toxic. Legislation now demands a positive closed system of ventilation. This makes the pollution from cylinder blow-by gases negligible. Positive crankcase ventilation is the solution to this problem.

In early types of closed-system crankcase ventilation, the lower pressure at the carburettor air cleaner was used to cause an airflow through the inside of the engine. The breather outlet was simply connected by a pipe to the air cleaner. This caused the crankcase gases to be circulated and then burned in the engine cylinders. A flame trap was included in the system to prevent a crankcase explosion if the engine backfired.

In modern closed systems, the much lower pressure within the inlet manifold is used to extract crankcase gases. This has to be controlled in most cases by a variable regulator valve or pressure conscious valve (PCV). The valve is fitted between the breather outlet and the inlet manifold. It consists of a spring-loaded plunger, which opens as the inlet manifold pressure reduces. When the engine is stationary, the valve is closed. Under normal running conditions, the valve opens to allow crankcase gases to enter the inlet manifold with minimum restriction. At low manifold pressures during idling and overrun (pressure is less than atmospheric), further travel of the valve plunger against its spring closes it in the opposite direction. This reduces gas flow to the inlet manifold. This feature makes sure that the fuel control process is not interfered with under these conditions. The valve also acts as a safety device in case of a backfire. Any high pressure created in the inlet manifold will close the valve completely. This will isolate the crankcase and prevent the risk of explosion.



Key fact

Crankcase emission systems are monitored by OBD.

6.23 Diagnostics – lubrication

6.23.1 Systematic testing

If the reported fault is that the oil pressure light comes on at low speed, proceed as follows:

1 Run the engine and see when the light goes off or comes on.
2 Is the problem worse when the engine is hot? Check the oil level. When was it last serviced?

Table 6.8 Tests and information required

Test carried out	Information required
Oil pressure	Oil pressure is measured in bars. A typical reading would be approximately 3
Crankcase pressure	By tradition pressures less than atmosphere are given in strange ways, such as, inches of mercury or inches of water! This is why I like to stick to absolute pressure and then base it on pressure, 1 bar is atmospheric pressure and so on. 2 bar is more than atmospheric pressure like in a tyre. The trouble is standards vary so make sure you compare like with like! Back to crankcase pressure – it should be less than atmospheric, check data
Oil condition	Recommended type of lubricant



Figure 6.75 Oil pressure testing kit

Safety first

Note: You should always refer to the manufacturer's instructions appropriate to the equipment you are using.

3 If oil level is correct, then you must investigate further.
4 Carry out an oil pressure test to measure the actual pressure.
5 If pressure is correct, then renew the oil pressure switch. If not, engine strip down is likely.
6 Run and test for leaks.

6.23.2 Test equipment

Oil pressure test gauge

This is a simple pressure gauge that can be fitted with suitable adapters into the oil pressure switch hole. The engine is then run and the pressure readings compared to data.

Vacuum gauge

A simple 'U' tube full of water is often used. This is connected to the oil dipstick tube and the engine is run. The gauge should show a pressure less than atmospheric (a partial vacuum). This checks the operation of the crankcase ventilation system (Figure 6.75).

6.23.3 Test results

Some of the information you may have to get from other sources such as data books or a workshop manual is listed in Table 6.8.

6.23.4 Lubrication fault diagnosis table 1

Symptom	Possible faults	Suggested action
Low oil pressure	Lack of oil Blocked filter Defective oil pump Defective oil pressure relief valve	Top up Renew oil and filter Renew after further tests Adjust if possible or renew
High crankcase pressure	Blocked crankcase breather Blocked hose Pressure blowing by pistons	Clean or replace Clean or renew hose Engine overhaul may be required
Loss of oil	Worn piston rings Leaks	Engine overhaul may be required Renew seals or gaskets

6.23.5 Lubrication fault diagnosis table 2

Symptom	Possible cause
Oil leaks	Worn oil seal (check breather system) Gasket blown Cam or rocker cover loose Oil filter seal
Blue smoke	Piston rings Valve stem seals Head gasket

6.24 Batteries

6.24.1 Safety

The following points must be observed when working with batteries:

- good ventilation;
- protective clothing;
- supply of water available (running water preferable);
- first-aid equipment available, including eyewash;
- no smoking or naked lights permitted.

6.24.2 Lead-acid batteries

Incremental changes over the years have made the sealed and maintenance-free battery, now in common use, very reliable and long-lasting. This may not always appear to be the case to some end users, but note that quality is often related to the price the customer pays. Many bottom-of-the-range cheap batteries with a 12-month guarantee will last for 13 months (Figure 6.76).



Figure 6.76 High-quality vehicle batteries(Source: Bosch Media)

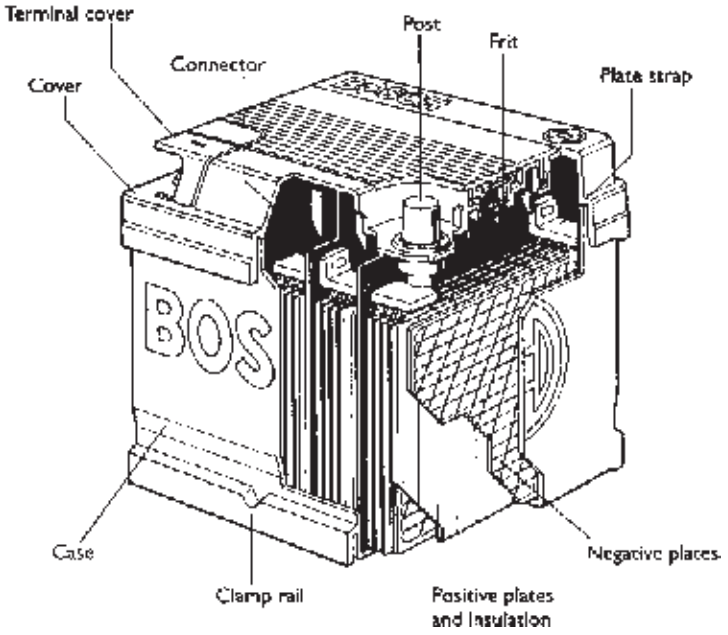


Figure 6.77 Vehicle battery components

The basic construction of a nominal 12 V lead-acid battery consists of six cells connected in series. Each cell producing approximately 2 V is housed in an individual compartment within a polypropylene or similar case. The active material is held in grids or baskets to form the positive and negative plates. Separators made from a microporous plastic insulate these plates from each other (Figure 6.77).

The grids, connecting strips and the battery posts are made from a lead alloy. For many years, this was lead antimony (PbSb), but this has now been largely replaced by lead calcium (PbCa). The newer materials cause less gassing of the electrolyte when the battery is fully charged. This has been one of the main reasons why sealed batteries became feasible as water loss is considerably reduced.

Modern batteries described as sealed do still have a small vent to stop the pressure build-up due to the very small amount of gassing. A further requirement of sealed batteries is accurate control of charging voltage.

6.24.3 Battery rating

In simple terms, the characteristics or rating of a particular battery are determined by how much current it can produce and how long it can sustain this current. The rate at which a battery can produce current is determined by the speed of the chemical reaction. This in turn is determined by a number of factors:

- surface area of the plates;
- temperature;
- electrolyte strength;
- current demanded.

The actual current supplied therefore determines the overall capacity of a battery. The rating of a battery has to specify the current output and the time (Table 6.9).

Table 6.9 Battery capacity ratings

Ampere-hour capacity	This describes how much current the battery is able to supply for either 10 or 20 hours. The 20-hour figure is the most common. For example, a battery quoted as being 44 Ah (Ampere-hour) will be able, if fully charged, to supply 2.2 A for 20 hours before being completely discharged (cell voltage above 1.75 V)
Reserve capacity	A system used now on all new batteries is reserve capacity. This is quoted as a time in minutes for which the battery will supply 25 A at 25 °C to a final voltage of 1.75 V per cell. This is used to give an indication of how long the battery could run the car if the charging system was not working. Typically, a 44 Ah battery will have a reserve capacity of approximately 60 minutes
Cold cranking Amps	Batteries are given a rating to indicate performance at high current output and at low temperature. A typical value of 170 means that the battery will supply this current for one minute at a temperature of −18 °C at which point the cell voltage will fall to 1 V (BS)

Cold cranking amps (CCA) capacity rating methods do vary to some extent: British standards, DIN standards and SAE standards are the three main examples:

- BS 60 seconds
- DIN 30 seconds
- SAE 30 seconds

In summary, the capacity of a battery is the amount of electrical energy that can be obtained from it over a set time. It is usually given in ampere-hours, reserve capacity (RC) and cold cranking amps.

- A 40 Ah battery means it should give 2 A for 20 hours.
- Reserve capacity indicates the time in minutes for which the battery will supply 25 A at 25 °C.
- Cold cranking current indicates the maximum battery current at −18 °C (0 °F) for a set time (standards vary).

A battery for normal light vehicle use may be rated as follows: 44 Ah, 60 RC and 170 A CCA (BS). A 'heavy-duty' battery will have the same Ah rating as its 'standard duty' counterpart, but it will have a higher CCA and RC.

Key fact

The capacity of a battery is the amount of electrical energy that can be obtained from it over a set time.

6.25 Diagnostics – batteries

6.25.1 Servicing batteries

In use a battery requires very little attention other than the following when necessary:

- Corrosion should be cleaned from terminals using hot water.
- Terminals should be smeared with petroleum jelly or Vaseline *not* ordinary grease.
- Battery tops should be clean and dry.
- If not sealed, cells should be topped up with distilled water 3 mm above the plates (not very common now).
- Battery should be securely clamped in position.

6.25.2 Maintenance-free

By far the majority of batteries now available are classed as 'maintenance-free'. This implies that little attention is required during the life of the battery. Earlier batteries and some heavier types do, however, still require the electrolyte level to be checked and topped up periodically. Battery posts are still a little prone to corrosion and hence the usual service of cleaning with hot water if appropriate and the application of petroleum jelly or proprietary terminal grease is still recommended. Ensuring that the battery case and in particular the top remains clean will help to reduce the rate of self-discharge.

The state of charge of a battery is still very important, and in general it is not advisable to allow the state of charge to fall below 70% for long periods as the sulphate on the plates can harden, making recharging diff cult. If a battery is to be stored for a long period (more than a few weeks), then it must be recharged every so often to prevent it from becoming sulphated. Recommendations vary, but a recharge every six weeks is a reasonable suggestion.

6.25.3 Charging

The recharging recommendations of battery manufacturers vary slightly. The following methods, however, are reasonably compatible and should not cause any problems. The eff ciency of a battery is not 100%. Therefore, the recharging process must 'put back' the same Ah capacity as was used on discharge plus a bit more to allow for eff ciency losses. It is therefore clear that the main question about charging is not how much, but at what rate.

The traditional recommendation was that the battery should be charged at a tenth of its Ah capacity for approximately 10 hours or less. This is based on the assumption that the Ah capacity is quoted at the 20-hour rate, as a tenth of this f gure will make allowance for the charge factor. This f gure is still valid but as Ah capacity is not always used nowadays, a different method of deciding the rate is necessary. One way is to set a rate at a sixteenth of the reserve capacity, again for up to 10 hours. The f nal suggestion is to set a charge rate at one-fortieth of the cold start performance f gure, also for up to 10 hours. Clearly if a battery is already half charged, half the time is required to recharge to full capacity.

Key fact

The ideal charge rate is determined as.

1/10 of the Ah capacity

1/16 of the RC.

1/40 of the CCA.

The above-suggested charge rates are to be recommended as the best way to prolong battery life. They do all, however, imply a constant current charging source. A constant voltage charging system is often the best way to charge a battery. This implies that the charger, an alternator on a car for example, is held at a constant level and the state of charge in the battery will determine how much current will f ow. This is often the fastest way to recharge a f at battery. If a constant voltage of less than 14.4 V is used, then it is not possible to cause excessive gassing and this method is particularly appropriate for sealed batteries.

Boost charging is a popular technique often applied in many workshops. It is not recommended as the best method but, if correctly administered and not repeated too often, it is suitable for most batteries. The key to fast or boost charging is that the battery temperature should not exceed 43 °C. With sealed batteries, it is particularly important not to let the battery gas excessively in order to prevent the build-up of pressure. A rate of about f ve times the 'normal' charge setting will bring the battery to 70–80% of its full capacity within approximately one hour. Table 6.10 summarises the charging techniques for a lead-acid battery.

Table 6.10 Charging methods

Charging method	Notes
Constant voltage	Constant voltage will recharge any battery in seven hours or less without any risk of overcharging (14.4 V maximum)
Constant current	Ideal charge rate can be estimated as 1/10 of Ah capacity, 1/16 of reserve capacity or 1/40 of cold start current (charge time of 10–12 hours or pro rata original state)
Boost charging	At no more than five times the ideal rate, a battery can be brought up to approximately 70% of charge in about one hour
Smart charging	Let the charger do all the calculations and all the work



Figure 6.78 Smart battery charger (Source: www.ctek.com)

Smart chargers

Nowadays, there are a number of 'Smart' or 'Intelligent' battery chargers that are able to determine the ideal rate from the battery voltage and the current it will accept. Some also have features such as a 'recond' mode, which allows you to correct the acid stratif cation that often occurs in deeply discharged batteries – particularly leisure batteries. Some key features of a charger produced by a company called Ctek are as follows (Figure 6.78):

- Safe: No sparks and cannot harm vehicle electrics, so no need to disconnect the battery.
- Suitable for all types of 12 V lead-acid batteries up to 150 Ah.
- Connect and forget – can be left connected for months – ideal for vehicles used occasionally.
- Analysis mode to check if battery can hold charge.
- 10 day f oat maintenance for maximum charge level.
- 'Recond' mode – special programme to revive deeply discharged batteries.
- Supply mode – can be used as a 12 V power source to protect electrical settings.

6.25.4 Battery faults

Any electrical device can suffer from two main faults: these are either open circuit or short circuit. A battery is no exception but can also suffer from other problems

Table 6.11 Battery faults

Symptom or fault	Likely causes					
Low state of charge	Charging system fault	Unwanted drain on battery	Electrolyte diluted	Incorrect battery for application		
Low capacity	Low state of charge	Corroded terminals	Impurities in the electrolyte	Sulphated	Old age – active material fallen from the plates	
Excessive gassing and temperature	Overcharging	Positioned too near exhaust component				
Short circuit cell	Damaged plates and insulators	Build-up of active material in sediment trap				
Open circuit cell	Broken connecting strap	Excessive sulphation	Very low electrolyte			
Service life shorter than expected	Excessive temperature	Battery has too low a capacity	Vibration excessive	Contaminated electrolyte	Long periods of not being used	Overcharging



Figure 6.79 Battery charger and engine starter (Source: Bosch Media)

Key fact

Repairing modern batteries is not possible.

such as low charge or low capacity. Often a problem, apparently with a vehicle battery, can be traced to another part of the vehicle such as the charging system. Table 6.11 lists all the common problems encountered with lead-acid batteries, together with typical causes (Figure 6.79).

Most of the problems listed previously will require the battery to be replaced. In the case of sulphation, it is sometimes possible to bring the battery back to life with a very long low current charge. A fortieth of the Ah capacity or about a two-hundredth of the cold start performance for approximately 50 hours is an appropriate rate. Some smart chargers are very good for this.

6.25.5 Testing batteries

For testing the state of charge of a non-sealed type of battery, it was traditional to use a hydrometer. The hydrometer is a syringe which draws electrolyte from a cell and a f oat which will f oat at a particular depth in the electrolyte according to its density. The relative density or specif c gravity is then read from the graduated scale on the f oat. A fully charged cell should show 1.280, when half charged 1.200 and if discharged 1.120.

Most vehicles are now f tted with maintenance-free batteries and a hydrometer cannot be used to f nd the state of charge. This can, however, be determined from the voltage of the battery, as given in Table 6.12. An accurate voltmeter is required for this test – note the misleading surface charge shown in Figure 6.80 (also see Figure 6.81).

To test a battery more thoroughly, it is now preferred to use a volt, amp tester (VAT). There are many variations on the market; however, this section will outline

Table 6.12 Battery voltages

Battery volts at 20 °C	State of charge
12.0V	Discharged (20% or less)
12.3V	Half charged (50%)
12.7V	Charged (100%)



Figure 6.80 Checking battery voltage. In this case, the engine had just been switched off so the reading shows a 'surface charge'



Figure 6.81 MicroVAT (Source: Snap-on)

Key fact

Accuracy: A good tip to reduce surface charge, is after switching off the engine, turn on the headlights for a few minutes, then turn them off, wait another few minutes – then take the reading.

just one type. Snap-on produce a compact and very useful tester called the MicroVAT. This equipment will carry out a range of diagnostic tests.

The device, as with many similar types, will do not only battery condition tests but also tests on the charging and starting system.

This VAT takes advantage of new impedance/current test technology to detect the full range of battery failure modes including bad cells, sulphation, internal short circuits, and other chemical and physical failures. Testing takes less than f ve seconds and will even work on batteries discharged down to as low as 1 V.

Some of the key features of this tester are as follows:

- automated system test of battery, alternator and starter in under a minute;
- detailed test data: alternator ripple, internal resistance, starter draw, state of charge, charging amps, and volts;
- tests discharged batteries down to 1 V;
- impedance/current (IC) test technology;
- wireless printer option;
- integrated high and low amp probe options.

The MicroVAT uses a fan-cooled 50 A load and integrated amp probe to test the quantity and quality of alternator output with an alternator ripple test. Many late-model computer-controlled charging systems virtually shut down under no-load conditions. Diagnostic tests that can be carried out with this tester, when an amps probe is also used, are as follows:

Starting test data

- Average cranking current
- Maximum cranking current
- Pre-set voltage
- Pre-set load voltage
- Average cranking voltage
- Minimum cranking voltage

Battery test data

- Diagnosis
- Actual CCA
- Percentage capacity
- Open circuit voltage
- Impedance (often described as internal resistance)

Alternator test data

- Diagnosis
- Failure mode
- Charging at idle
- Charging volts under load
- Average current at idle
- Peak current
- Peak-to-peak ripple at idle
- Peak-to-peak ripple under load.

6.26 Starting

6.26.1 Starter circuit

In comparison with most other circuits on the modern vehicle, the starter circuit is relatively simple. The problem to overcome, however, is that of volt drop in the main supply wires. A spring-loaded key switch usually operates the starter; the same switch also controls the ignition and accessories. The supply from the key switch, via a relay in many cases, causes the starter solenoid to operate and this in turn, by a set of contacts, controls the heavy current. In some cases, an extra terminal on the starter solenoid provides an output when cranking, usually used to bypass a dropping resistor on the ignition or fuel pump circuits. The problem of volt drop in the main supply circuit is due to the high current required by the starter, particularly under adverse starting conditions such as very low temperatures.

A typical cranking current for a light vehicle engine is in the order of 150 A, but this may peak in excess of 500 A to provide the initial stalled torque. It is generally accepted that a maximum volt drop of only 0.5 V should be allowed between the battery and starter when operating. An Ohm's law calculation indicates that the maximum allowed circuit resistance is 2.5 mΩ, when using a 12 V supply. This is a worst-case situation and lower resistance values are used in most applications. The choice of suitable conductors is therefore very important (Figure 6.82).

Key fact

A typical cranking current for a light vehicle engine is approximately 150 A, but this may peak in excess of 500A to provide the initial stalled torque.

6.26.2 Inertia starters

In all standard motor vehicle applications, it is necessary to connect the starter to the engine ring gear only during the starting phase. If the connection remained permanent, the excessive speed at which the starter would be driven by the engine would destroy the motor almost immediately. The inertia type of starter motor was the technique used for many years, but it is now redundant.

The starter engages with the f ywheel ring gear by means of a small pinion. The toothed pinion and a sleeve splined on to the armature shaft are threaded such that when the starter is operated via a remote relay, the armature will cause the sleeve to rotate inside the pinion. The pinion remains still due to its inertia and,

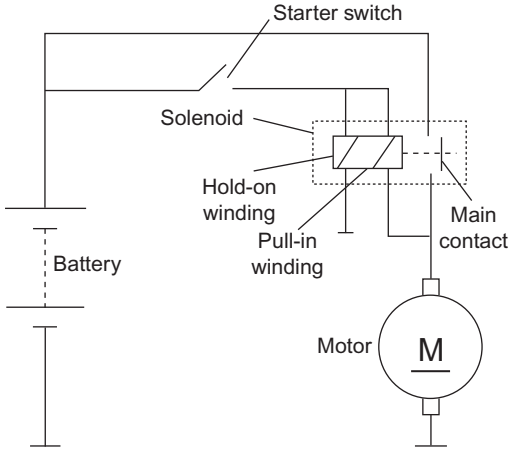


Figure 6.82 Starter circuit

because of the screwed sleeve rotating inside it, the pinion is moved into mesh with the ring gear.

When the engine f res and runs under its own power, the pinion is driven faster than the armature shaft. This causes the pinion to be screwed back along the sleeve and out of engagement with the f ywheel. The main spring acts as a buffer when the pinion f rst takes up the driving torque and also acts as a buffer when the engine throws the pinion back out of mesh.

6.26.3 Pre-engaged starters

Key fact

Pre-engaged starters provide a positive engagement with the ring gear, as full power is not applied until the pinion is fully in mesh.

Pre-engaged starters are f tted to the majority of vehicles in use today. They provide a positive engagement with the ring gear, as full power is not applied until the pinion is fully in mesh. They prevent premature ejection as the pinion is held into mesh by the action of a solenoid. A one-way clutch is incorporated into the pinion to prevent the starter motor being driven by the engine.

Figure 6.83 shows the circuit associated with operating this type of pre-engaged starter. The basic operation of the pre-engaged starter is as follows. When the key switch is operated, a supply is made to terminal 50 on the solenoid. This causes two windings to be energised: the hold-on winding and the pull-in winding. Note that the pull-in winding is of very low resistance and hence a high current f ows. This winding is connected in series with the motor circuit and the current f owing will allow the motor to rotate slowly to facilitate engagement. At the same time, the magnetism created in the solenoid attracts the plunger and via an operating lever pushes the pinion into mesh with the f ywheel ring gear. When the pinion is fully in mesh, the plunger at the end of its travel causes a heavy-duty set of copper contacts to close. These contacts now supply full battery power to the main circuit of the starter motor. When the main contacts are closed, the pull-in winding is effectively switched off due to equal voltage supply on both ends. The hold-on winding holds the plunger in position as long as the solenoid is supplied from the key switch.



Figure 6.83 Inertia engagement starter and solenoid switch

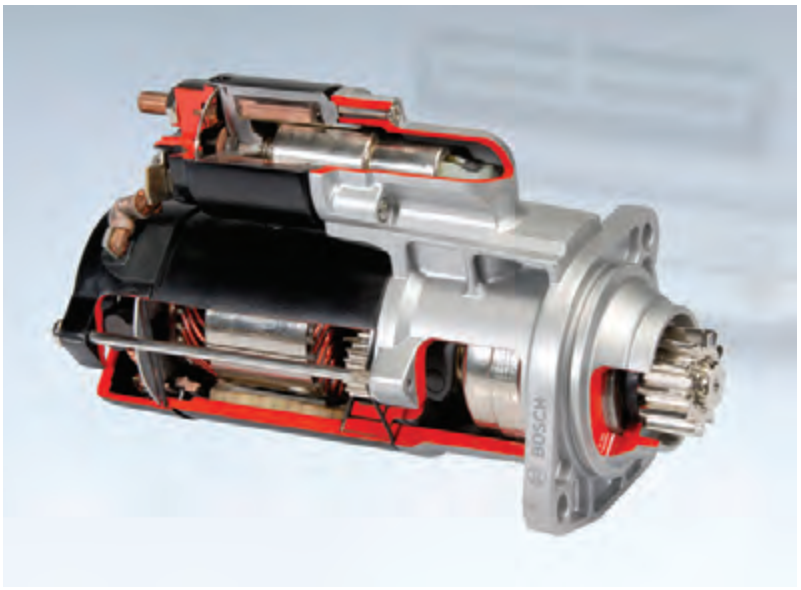


Figure 6.84 Intermediate transmission starter(Source: Bosch Media)

When the engine starts and the key is released, the main supply is removed and the plunger and pinion return to their rest positions under spring tension. A lost motion spring located on the plunger ensures that the main contacts open before the pinion is retracted from mesh (Figure 6.84).

During engagement if the teeth of the pinion hit the teeth of the f ywheel (tooth-to-tooth abutment), the main contacts are allowed to close due to the engagement spring being compressed. This allows the motor to rotate under power and the pinion will slip into mesh.

The torque developed by the starter is passed through a one-way clutch to the ring gear. The purpose of this free-wheeling device is to prevent the starter being driven at excessively high speed if the pinion is held in mesh after the engine has started. The clutch consists of a driving and driven member with several rollers in between the two. The rollers are spring loaded and either wedge-lock the two members together by being compressed against the springs, or free wheel in the opposite direction.

Many variations of pre-engaged starter are in common use, but all work on similar lines to the above description. The wound f eld type of motor is replaced by the permanent magnet version for many applications.

6.26.4 Permanent magnet starters

Permanent magnet starters began to appear on production vehicles in the late 1980s. The two advantages of these motors, compared to conventional types, are less weight and smaller size. This makes the permanent magnet starter a popular choice by vehicle manufacturers, as due to the lower lines of today's cars, less space is now available for engine electrical systems. The reduction in weight provides a contribution towards reducing fuel consumption.

The principle of operation is similar in most respects to the conventional pre-engaged starter motor, the main difference being the replacement of f eld windings and pole shoes with high-quality permanent magnets. The reduction in weight is in the region of 15% and the diameter of the yoke can be reduced by a similar factor.

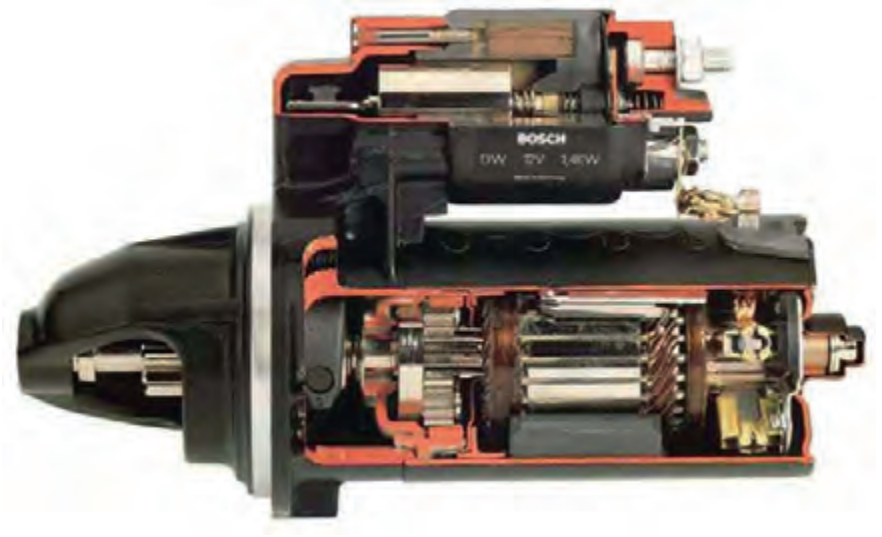


Figure 6.85 Permanent magnet fields are used in this starter motor

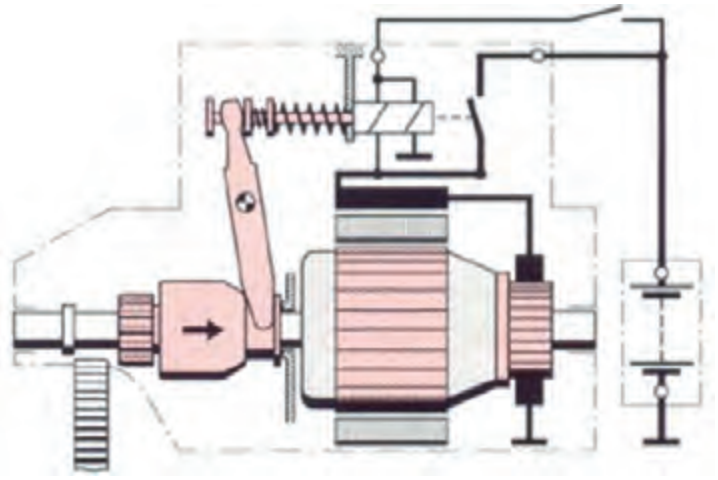


Figure 6.86 Starter circuit and engagement mechanism

Permanent magnets provide constant excitation and it would be reasonable to expect the speed and torque characteristic to be constant. However, owing to the fall in battery voltage under load and the low resistance of the armature windings, the characteristic is comparable to series wound motors.

Development by some manufacturers has also taken place in the construction of the brushes. A copper and graphite mix is used, but the brushes are made in two parts, allowing a higher copper content in the power zone and a higher graphite content in the commutation zone. This results in increased service life and a reduction in volt drop giving improved starter power (Figure 6.85).

Key fact

For applications with a higher power requirement, permanent magnet starter motors have an intermediate transmission.

For applications with a higher power requirement, permanent magnet motors with intermediate transmission have been developed. This allows the armature to rotate at a higher and more eff cient speed while still providing the torque, due to the gear reduction. Permanent magnet starters with intermediate transmission are available with power outputs of approximately 1.7 kW, suitable for spark ignition engines up to approximately 5 L or compression ignition engines up to approximately 1.6 L. This form of permanent magnet motors can give a weight saving of up to 40%. The principle of operation is again similar to the conventional pre-engaged starter (Figure 6.86).

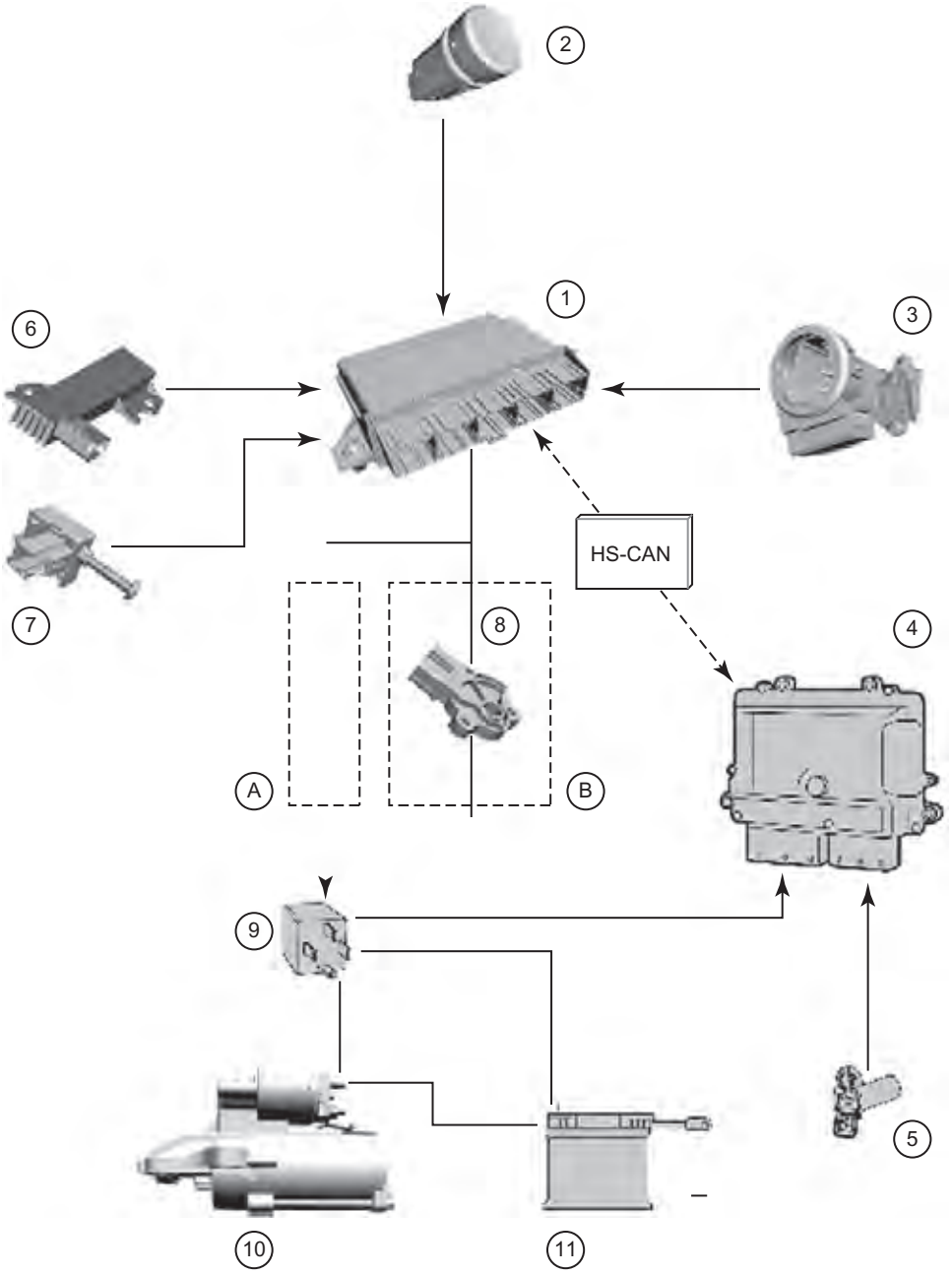


Figure 6.87 Keyless starting system: 1 – keyless vehicle module; 2 – start/stop button; 3 – electronic steering lock; 4 – powertrain control module; 5 – crank sensor; 6 – keyless vehicle antenna; 7 – vehicles with manual transmission: clutch pedal position switch/vehicles with automatic transmission: stoplamp switch; 8 – the TR sensor; 9 – starter relay; 10 – starter motor; 11 – battery (Source: Ford Motor Company)

The sun gear is on the armature shaft and the planet carrier drives the pinion. The ring gear or annulus remains stationary and also acts as an intermediate bearing. This arrangement of gears gives a reduction ratio of approximately 5:1.

6.26.5 Keyless starting system

In the Ford diagram shown in Figure 6.87, the powertrain control module (PCM) allows the engine to start, only when the passive anti-theft system (PATS) reads

Key fact

On a key-free system, the key-free module switches on the control voltage for the starter relay

a key which transmits a valid code. On a key-free vehicle, the passive key is recognized by the key-free module and if the key is valid the permission to start is issued directly. On vehicles with a manual transmission, it is necessary to depress the clutch pedal; on those with automatic transmission, the brake pedal must be pressed. On a key-free system, the key-free module switches on the control voltage for the starter relay.

The PCM switches the ground in the control circuit of the starter relay which then connects power through to the starter solenoid. As soon as the speed of the engine has reached 750 rpm or the maximum permitted start time of 30 seconds has been exceeded, the PCM switches off the starter relay and therefore the starter motor. This protects the starter. If the engine does not turn or turns only slowly, the starting process is aborted by the PCM.

Key fact

Faults on key-free systems can be diagnosed using standard equipment, but a suitable scanner is almost essential.

6.27 Diagnostics – starting

6.27.1 Circuit testing procedure

The process of checking a 12 V starting system operation is shown in Figure 6.88.

The idea of these tests is to see if the circuit is supplying all the available voltage at the battery to the starter. If it is, then the starter is at fault, if not, then the circuit is at fault. The numbered voltmeters relate to the number of the test in the above list (Figure 6.89).

Note that connections to the starter should be made to the link between the solenoid contacts and the motor, not to the main supply terminal (Figure 6.90).

6.27.2 Starting fault diagnosis table

Symptom	Possible fault
Engine does not rotate when trying to start	Battery connection loose or corroded Battery discharged or faulty Broken loose or disconnected wiring in the starter circuit Defective starter switch or automatic gearbox inhibitor switch Starter pinion or flywheel ring gear loose Earth strap broken. Loose or corroded
Starter noisy	Starter pinion or flywheel ring gear loose Starter mounting bolts loose Starter worn (bearings, etc.) Discharged battery (starter may jump in and out)
Starter turns engine slowly	Discharged battery (slow rotation) Battery terminals loose or corroded Earth strap or starter supply loose or disconnected High resistance in supply or earth circuit Internal starter fault

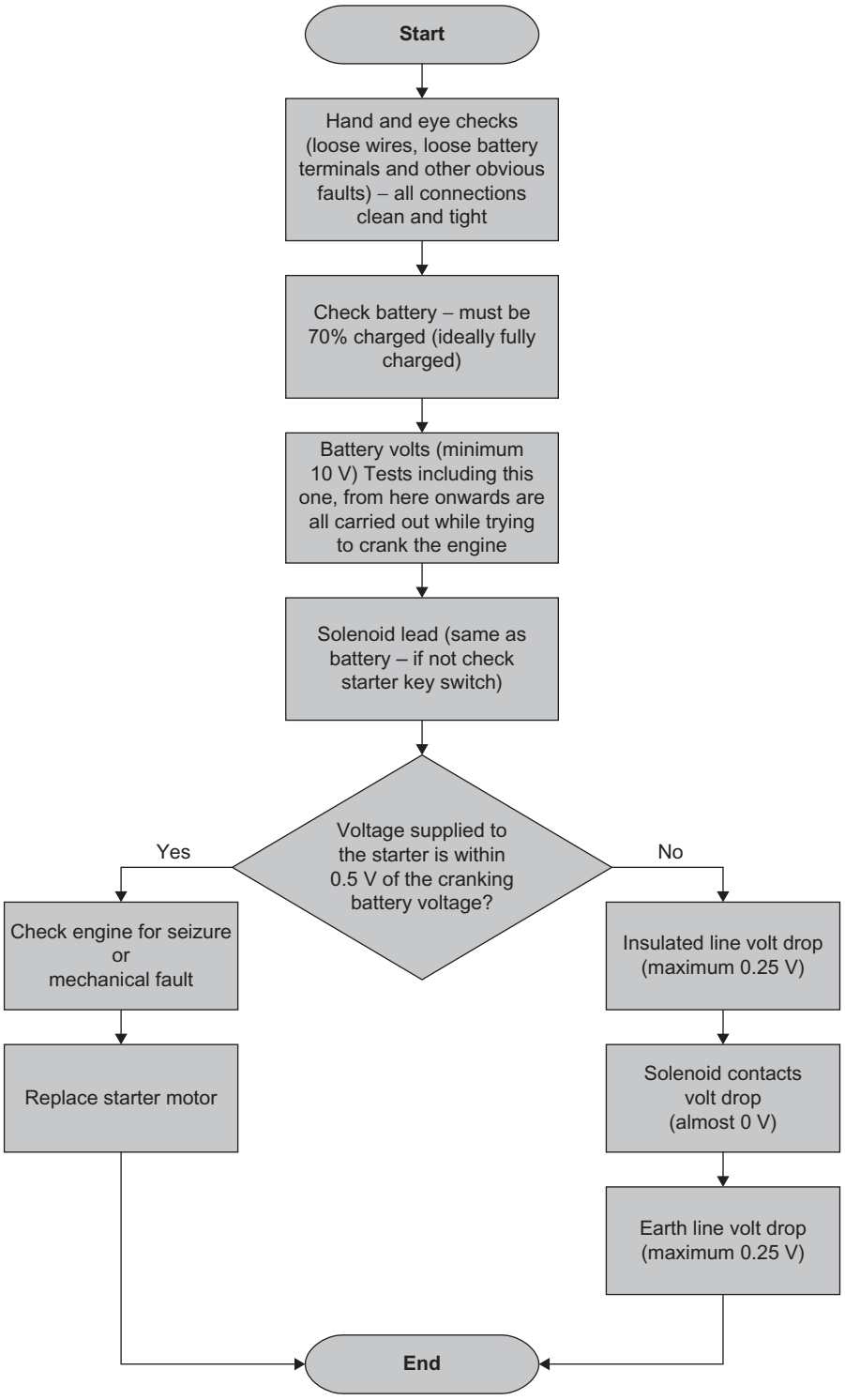


Figure 6.88 Starting system diagnosis chart

6.28 Charging

6.28.1 Introduction

The 'current' demands made by modern vehicles are considerable. The charging system must be able to meet these demands under all operating conditions and still fast charge the battery (Figure 6.91).

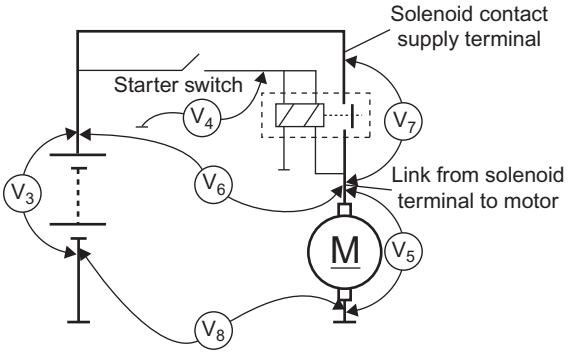


Figure 6.89 Starter circuit testing

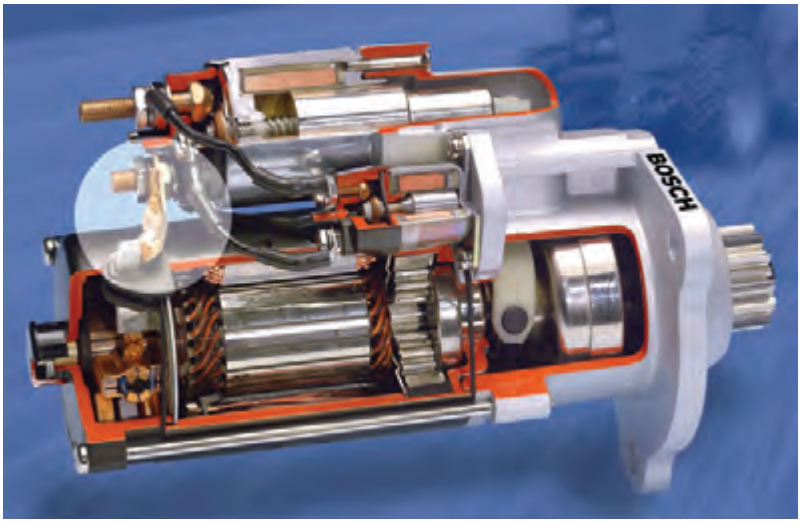


Figure 6.90 The link from the solenoid contacts and the motor is highlighted in this image

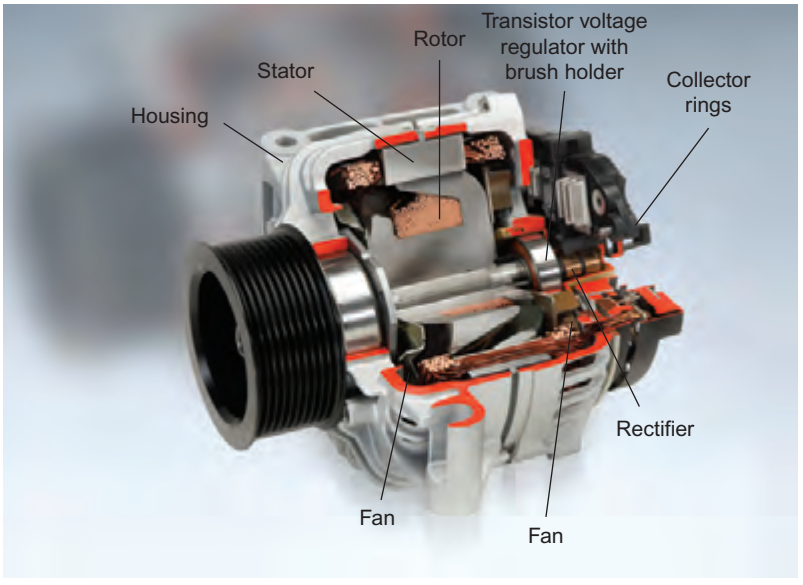


Figure 6.91 Alternator components

The main component of the charging system is the alternator and on most modern vehicles, with the exception of its associated wiring, it is the only component in the charging system. The alternator generates AC but must produce DC at its output terminal, as only DC can be used to charge the battery and run electronic circuits. The output of the alternator must be a constant voltage regardless of engine speed and current load.

The charging system must meet the following criteria (when the engine is running):

- supply the current demands made by some or all loads;
- supply whatever charge current the battery demands;
- operate at idle speed;
- constant voltage under all conditions;
- eff cient power to weight ratio;
- reliable, quiet, resistance to contamination;
- low maintenance;
- provide indication of correct operation.

Key fact

An alternator generates AC but must produce DC at its output terminal, as only DC can be used to charge the battery and run electronic circuits.

6.28.2 Basic principles

When the alternator voltage is less than the battery (engine slow or not running for example), the direction of current f ow is from the battery to the vehicle loads. The alternator diodes prevent current f owing into the alternator. When the alternator output is greater than the battery voltage, current will f ow from the alternator to the vehicle loads and the battery.

It is clear, therefore, that the alternator output voltage must be above battery voltage at all times when the engine is running. The actual voltage used is critical and depends on a number of factors.

The main consideration for charging voltage is the battery terminal voltage when fully charged. If the charging system voltage is set to this value, then there can be no risk of overcharging the battery. This is known as the constant voltage charging technique. The f gure of 14.2 $\pm$ 0.2 V is the accepted charging voltage for a 12 V system. Commercial vehicles generally employ two batteries in series at a nominal voltage of 24 V; therefore, the accepted charge voltage would be doubled. These voltages are used as the standard input for all vehicle loads. For the purpose of clarity, the text will just consider a 12 V system.

The other areas for consideration when determining charging voltage are any expected volt drops in the charging circuit wiring and the operating temperature of the system and battery. The voltage drops must be kept to a minimum, but it is important to note that the terminal voltage of the alternator may be slightly above that supplied to the battery.

Key fact

In order to full-wave rectify the output of a three-phase machine, six diodes are needed.

6.28.3 Rectif cation of AC to DC

In order to full-wave rectify the output of a three-phase machine, six diodes are needed. These are connected in the form of a bridge, which consists of three positive diodes and three negative diodes. The output produced by this conf guration is shown compared to the three phase signals (Figure 6.92).

Three positive f eld diodes are usually included in a rectif er pack. These are often smaller than the main diodes and are only used to supply a small current back to the f eld windings in the rotor. The extra diodes are known as the auxiliary, f eld or excitation diodes.

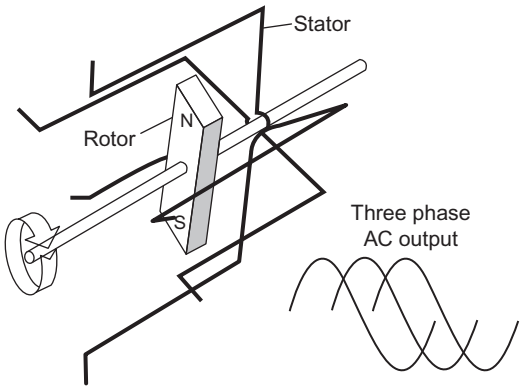


Figure 6.92 Alternator principle

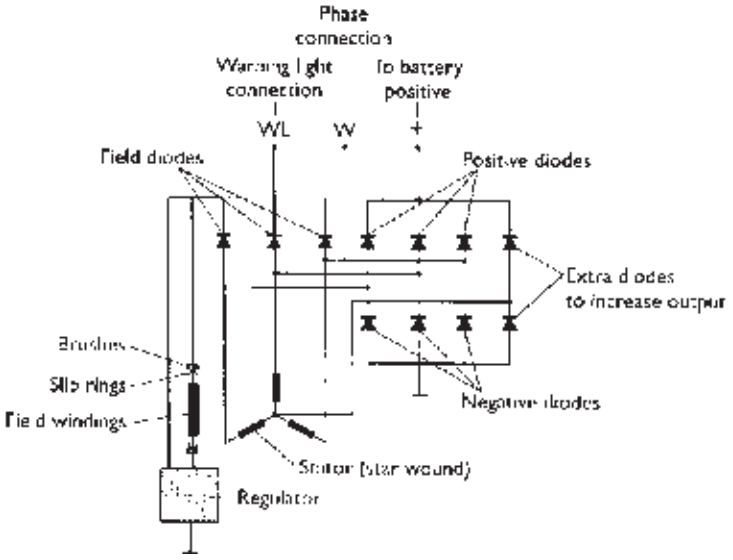


Figure 6.93 Alternator internal circuit

When a star wound stator is used, the addition of the voltages at the neutral point of the star is in theory 0 V. In practice, however, due to slight inaccuracies in the construction of the stator and rotor, a potential develops at this point. By employing two extra diodes, one positive and one negative connected to the star point, the energy can be collected. This can increase the power output of an alternator by up to 15%.

Figure 6.93 shows the full circuit of an alternator using an eight-diode main rectifier and three field diodes. The voltage regulator, which forms the starting point for the next section, is also shown in this diagram. The warning light in an alternator circuit, in addition to its function in warning of charging faults, also acts to supply the initial excitation to the field windings. An alternator will not always self-excite as the residual magnetism in the fields is not usually enough to produce a voltage which will overcome the 0.6 or 0.7 V needed to forward bias the rectifier diodes. A typical wattage for the warning light bulb is 2 W. Many manufacturers also connect a resistor in parallel with the bulb to assist in excitation and allow operation if the bulb blows. The charge warning light bulb is extinguished when the alternator produces an output from the field diodes, as this causes both sides of the bulb to take on the same voltage (a potential difference across the bulb of 0 V).

6.28.4 Regulation of output voltage

To prevent the vehicle battery from being overcharged, the regulated system voltage should be kept below the gassing voltage of the lead-acid battery. A figure of 14.2 ± 0.2 V is used for all 12 V charging systems. Accurate voltage control is vital with the ever-increasing use of electronic systems. It has also enabled the wider use of sealed batteries, as the possibility of overcharging is minimal.

Voltage regulation is a difficult task on a vehicle alternator because of the constantly changing engine speed and loads on the alternator. The output of an alternator without regulation would rise linearly in proportion with engine speed. Alternator output is also proportional to magnetic field strength and this in turn is proportional to the field current. It is the task of the regulator to control this field current in response to alternator output voltage. The abrupt switching of the field current does not cause abrupt changes in output voltage due to the very high inductance of the field (rotor) windings. The whole switching process also only takes a few milliseconds.

Regulators can be mechanical or electronic, the latter now almost universal on modern cars. The mechanical type uses a winding connected across the output of the alternator. The magnetism produced in this winding is proportional to output voltage. A set of normally closed contacts is attached to an armature, which is held in position by a spring. The supply to the field windings is via these contacts. When the output voltage rises beyond a pre-set level, say 14 V, the magnetism in the regulator winding will overcome spring tension and open the contacts. This switches off the field correct and causes alternator output to fall. As output falls below a pre-set level, the spring will close the regulator contacts again and so the process continues.

The problem with mechanical regulators is the wear on the contacts and other moving parts. This has been overcome with the use of electronic regulators which, due to more accurate tolerances and much faster switching, are far superior, producing a more stable output. Owing to the compactness and vibration resistance of electronic regulators, they are now fitted almost universally on the alternator reducing the number of connecting cables required.

The key to electronic voltage regulation is the Zener diode. This diode can be constructed to break down and conduct in the reverse direction at a precise level. This is used as the sensing element in an electronic regulator (Figure 6.94).

Electronic regulators can be made to sense either the battery voltage or the machine voltage (alternator) or a combination of the two. Most systems in use at present tend to be machine sensed, as this offers some protection against overvoltage in the event of the alternator being driven with the battery disconnected.

Overvoltage protection is required in some applications to prevent damage to electronic components. When an alternator is connected to a vehicle battery system voltage, even in the event of regulator failure, will not often exceed approximately 20 V due to the low resistance and swamping effect of the battery. If an alternator is run with the battery disconnected (which is not recommended), a heavy-duty Zener diode connected across the output will offer some protection as, if the system voltage exceeds its breakdown figure, it will conduct and cause the system voltage to be kept within reasonable limits. This device is often referred to as a surge protection diode.

Key fact

A figure of 14.2± 0.2 V is used for all 12V charging systems – except a few that have a smart charging system – check data.

Key fact

Electronic regulators sense either the battery voltage or the machine voltage (alternator) or a combination of the two.

6.28.5 Charging circuits

On many applications, the charging circuit is one of the simplest on the vehicle. The main output is connected to the battery via suitable size cable (or in some



Figure 6.94 Voltage regulator and brush box

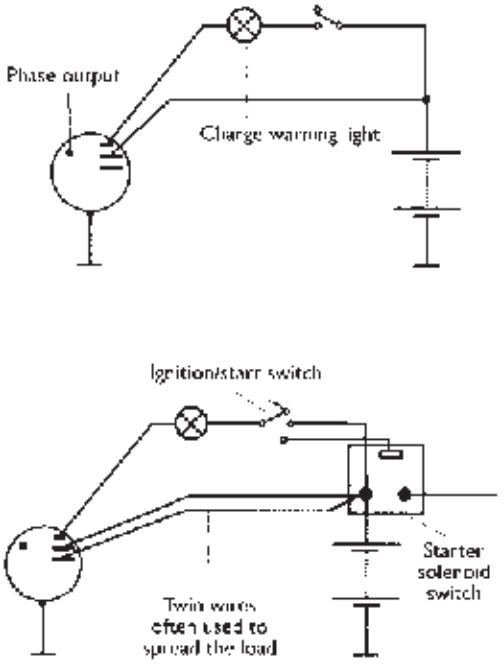


Figure 6.95 Example charging circuits

cases two cables to increase reliability and f exibility). The warning light is connected to an ignition supply on one side and to the alternator terminal at the other. A wire may also be connected to the phase terminal if it is utilised. Note that the output of the alternator is often connected to the starter main supply simply for convenience of wiring. If the wires are kept as short as possible, this will reduce voltage drop in the circuit. The volt drop across the main supply wire when the alternator is producing full output current should be less than 0.5 V (Figure 6.95).

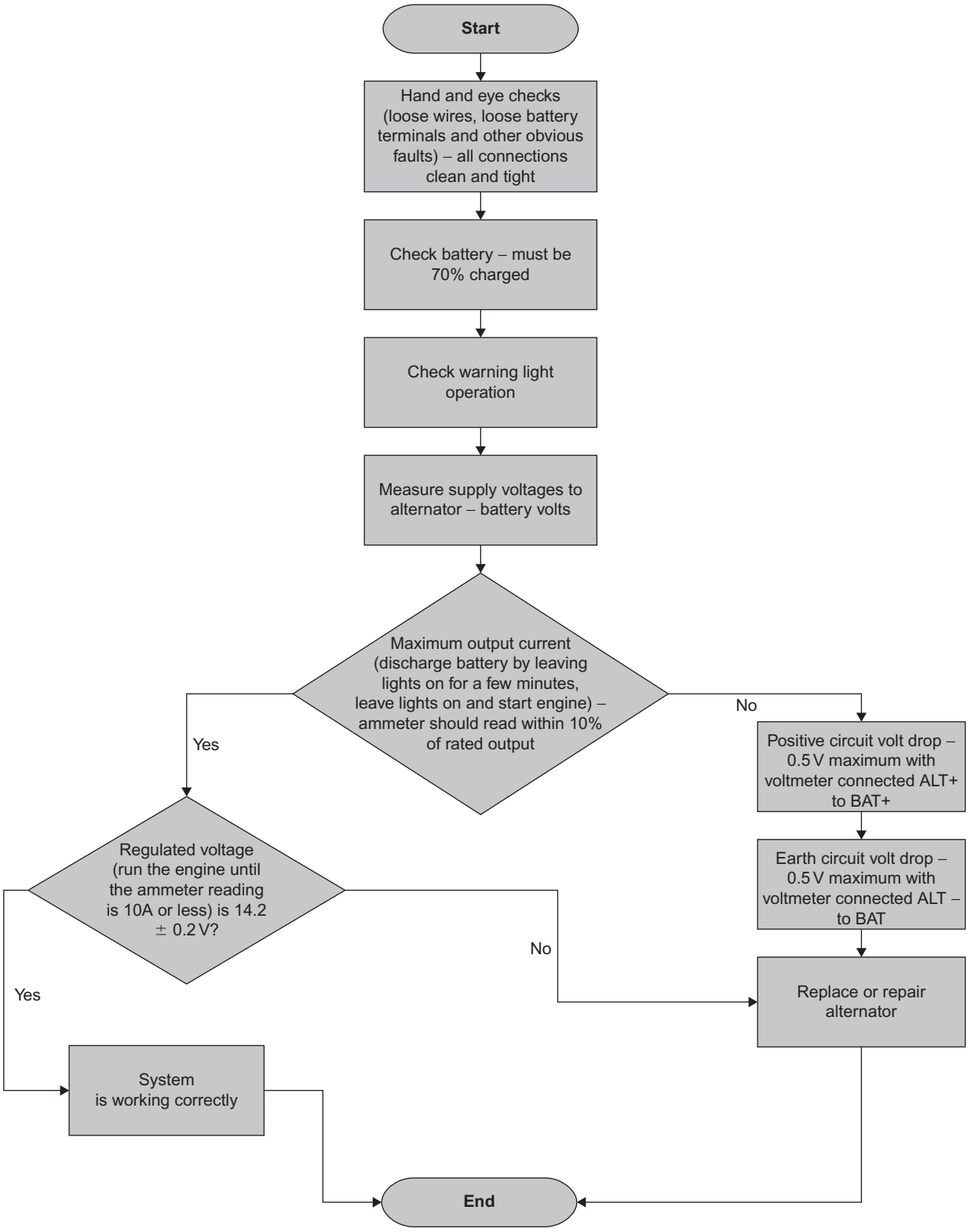


Figure 6.96 Charging system diagnosis chart

Some systems have an extra wire from the alternator to 'sense' battery voltage directly. An ignition feed may also be found and this is often used to ensure instant excitement of the f eld windings. A number of vehicles link a wire from the engine management ECU to the alternator. This is used to send a signal to increase engine idle speed if the battery is low on charge.

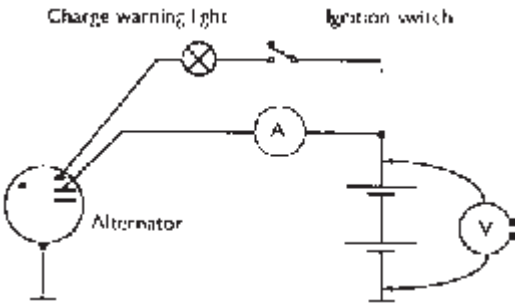


Figure 6.97 Alternator circuit testing

6.29 Diagnostics – charging

6.29.1 Testing procedure

After connecting a voltmeter across the battery and an ammeter in series with the alternator output wire(s), the process of checking the charging system operation is as shown in Figure 6.96.

If the alternator is found to be defective, then a quality replacement unit is the normal recommendation. Repairs are possible but only if the general state of the alternator is good (Figure 6.97).

6.29.2 Charging fault diagnosis table

Symptom	Possible fault
Battery loses charge	Defective battery Slipping alternator drive belt Battery terminals loose or corroded Alternator internal fault (diode open circuit, brushes worn or regulator fault, etc.) Open circuit in alternator wiring, either main supply, ignition or sensing wires fitted Short circuit component causing battery drain even when all switches are off High resistance in the main charging circuit
Charge warning light stays on when engine is running	Slipping or broken alternator drive belt Alternator internal fault (diode open circuit, brushes worn or regulator fault, etc.) Loose or broken wiring/connections
Charge warning light does not come on at any time	Alternator internal fault (brushes worn open circuit or regulator fault, etc.) Blown warning light bulb Open circuit in warning light circuit

CHAPTER

Chassis systems

7.1 Brakes

7.1.1 Introduction

The main braking system of a car works by hydraulics. This means that when the driver presses the brake pedal, liquid pressure forces pistons to apply brakes on each wheel. A handbrake system, usually operated by a lever and cables, is used for parking. Most handbrakes operate on the rear wheels (Figure 7.1).

Two types of light vehicle brakes are used. Disc brakes were traditionally used on the front wheels of cars but now are used on all four wheels of most modern vehicles. Braking pressure forces brake pads against both sides of a steel disc. Drum brakes are fitted on the rear wheels of some cars and on all wheels of older vehicles. Braking pressure forces brake shoes to expand outwards into contact with a drum. The important part of brake pads and shoes is a friction lining that grips well and withstands wear.

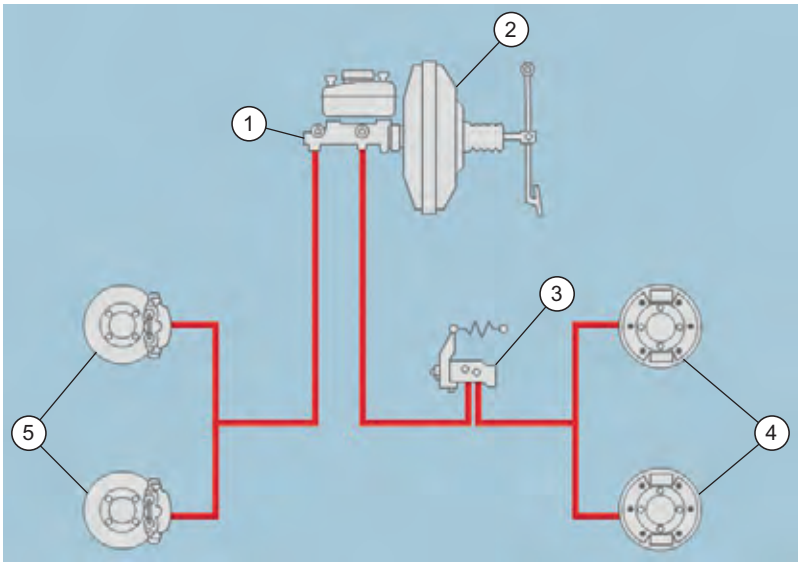


Figure 7.1 Brake system: 1 – master cylinder; 2 – brake vacuum booster; 3 – pressure regulator; 4 – brake shoes; 5 – brake discs (rotors) and pads

Advanced Automotive Fault Diagnosis.
© 2012 Tom Denton. Published by Routledge. All rights reserved.

7.1.2 Principle of hydraulic braking

A complete system includes a master cylinder operating several wheel cylinders. The system is designed to give the power amplif cation needed for braking the particular vehicle. On any vehicle, when braking, a lot of the weight is transferred to the front wheels. Most braking effort is therefore designed to work on the front brakes. Some cars have special hydraulic valves to limit rear wheel braking. This reduces the chance of the rear wheels locking and skidding.

The main benef ts of hydraulic brakes are as follows:

- almost immediate reaction to pedal pressure (no free play as with mechanical linkages);
- automatic even pressure distribution (f uid pressure effectively remains the same in all parts of the system);
- increase in force (liquid lever).

Caution and regular servicing is required to ensure the following:

- no air must be allowed in the hydraulic circuits (air compresses and would not transfer the force);
- correct adjustment must be maintained between shoe linings to drums and pads to discs (otherwise the pedal movement would be too large);
- lining materials must be free from contamination (such as oil, grease or brake f uid).

Key fact

Most braking systems have a separate mechanical brake which is a good safety feature.

A separate mechanical system is a good safety feature. Most vehicles have the mechanical handbrake working on the rear wheels but a few have it working on the front – take care.

Note the importance of f exible connections to allow for suspension and steering movement. These f exible pipes are made of high-quality rubber and are covered in layers of strong mesh to prevent expansion when under pressure.

Extra safety is built into braking systems by using a double-acting master cylinder (Figure 7.2). This is often described as tandem and can be thought of as two cylinders in one housing. The pressure from the pedal acts on both cylinders

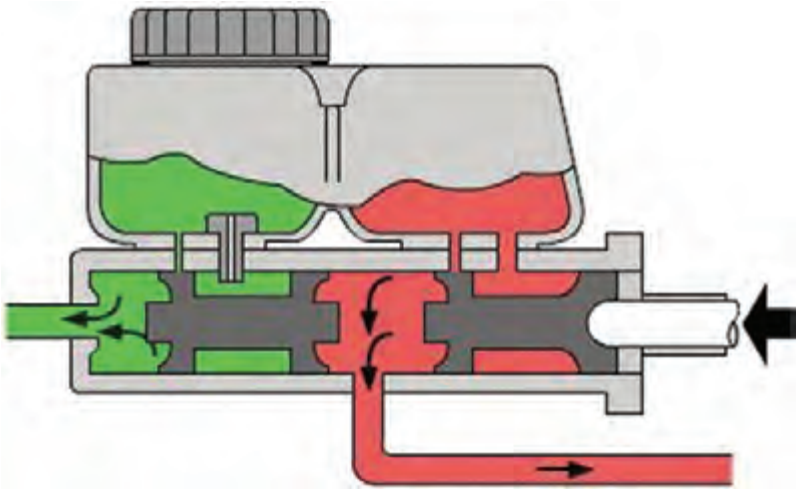


Figure 7.2 Master cylinder operation

but f uid cannot pass from one to the other. Each cylinder is then connected to a complete circuit. This can be by a number of methods:

- diagonal split;
- separate front and rear;
- duplicated front.

7.1.3 Disc and drum brake systems

Figure 7.3 shows a typical disc brake, calliper pads and disc. The type shown is known as single-acting sliding calliper. This is because only one cylinder is used but pads are still pressed equally on both sides of the disc by the sliding action. Disc brakes keep cooler because they are in the airstream and only part of the disc is heated as the brakes are applied. They also throw off water better than drum brakes. In most cases, servicing is minimal. Disc brakes are self-adjusting, and replacing pads is usually a simple task. In the type shown, just one bolt has to be removed to hinge the calliper upwards (Figure 7.4).

Key fact

Disc brakes are self-adjusting.

Disc brakes provide for good braking and are less prone to brake fade than drum brakes. This is because they are more exposed and can get rid of heat more easily. Brake fade occurs when the brakes become so hot that they cannot transfer energy any more and stop working. This type of problem can happen, for example, after keeping the car brakes on for a long time when travelling down a long steep hill. This is why a lower gear should be used to employ the engine as a brake. It is clearly important to use good-quality pads and linings because inferior materials can fail if overheated.



Figure 7.3 Brake caliper and ventilated disc (rotor)

Drum brakes operate by shoes being forced onto the inside of the drum. Shoes can be moved by double- or single-acting cylinders. The most common layout is to use one double-acting cylinder and brake shoes on each rear wheel of the vehicle, and disc brakes on the front wheels. A double-acting cylinder simply means that as f uid pressure acts through a centre inlet, pistons are forced out of both ends.

Key fact

Drum brakes are more affected by wet and heat than disc brakes because both water and heat are trapped inside the drum.



Figure 7.4 Drum brakes showing the shoes and wheel cylinder

7.1.4 Brake adjustments

Brakes must be adjusted so that the minimum movement of the pedal starts to apply the brakes. The adjustment in question is the gap between the pads and disc and/or the shoes and drum.

Disc brakes are self-adjusting because as pressure is released it moves the pads just away from the disc. Drum brakes are different because the shoes are moved away from the drum to a set position by a pull off spring. The set position is adjustable and this can be done in a number of ways.

- Self-adjusting drum brakes are almost universal now. On light vehicles, a common type uses an offset ratchet which clicks to a wider position if the shoes move beyond a certain amount when operated. Modern cars frequently have a self-adjusting handbrake.
- Screwdriver adjustment through a hole in the wheel and drum is also used. This is often a type of nut on a threaded bar which pushes the shoes out as it is screwed along the thread. This method can also have an automatic adjuster f tted.
- An adjustment screw on the back plate is now quite an old method in which a screw or square head protruding from the back plate moves the shoes by a snail cam.

Key fact

You must ensure that the brakes are not rubbing as this would build up heat and wear the friction material very quickly

The adjustment procedure stated by the manufacturer must be followed. As a guide, though, most recommend tightening the adjuster until the wheels lock and then moving it back until the wheel is just released. You must ensure that the brakes are not rubbing as this would build up heat and wear the friction material very quickly. As an aid to fault diagnosis, the effects of incorrect adjustment are as follows:

- reduced braking eff ciency;
- unbalanced braking;
- excessive pedal travel.

Key fact

Servo systems are designed to give little assistance for light braking but increase the assistance as pedal pressure is increased.

7.1.5 Servo-assisted braking

Servo systems are designed to give little assistance for light braking but increase the assistance as pedal pressure is increased. A common servo system uses low pressure (vacuum) from the manifold on one side, and the higher atmospheric pressure on the other side of a diaphragm. The low pressure is taken via a non-return safety valve from the engine inlet manifold. This pressure difference causes a force, which is made to act on the master cylinder (Figure 7.5).

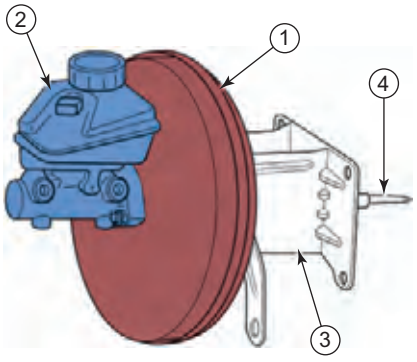


Figure 7.5 Servo unit: 1 – brake servo (booster); 2 – master cylinder and fluid reservoir; 3 – bracket; 4 – diaphragm rod connection to brake pedal

Hydraulic power brakes use the pressure from an engine-driven pump. This pump will often be the same one used to supply the power-assisted steering. Pressure from the pump is made to act on a plunger in line with the normal master cylinder. As the driver applies force to the pedal, a servo valve opens in proportion to the force applied by the driver. The hydraulic assisting force is therefore also proportional. This maintains the important 'driver feel'.

A hydraulic accumulator (a reservoir for f uid under pressure) is incorporated into many systems. This is because the pressure supplied by the pump varies with engine speed. The pressure in the accumulator is kept between set pressures in the region of 70 bar.

Warning: If you have to disconnect any components from the braking system on a vehicle f tted with an accumulator, you must follow the manufacturer's recommendations on releasing the pressure f rst.

7.1.5.1 Brake f uid

Always use new and approved brake f uid when topping up or renewing the system. The manufacturer's recommendations must always be followed. Brake f uid is hygroscopic, which means that over a period of time it absorbs water. This increases the risk of the f uid boiling due to the heat from the brakes. Pockets of steam in the system would not allow full braking pressure to be applied. Many manufacturers recommend that the f uid should be changed at regular intervals – in some cases once per year or every 30 000 km.

Safety f rst

Make sure the correct grade of fluid is used.

7.2 Diagnostics – brakes

7.2.1 Systematic testing

If the reported fault is the handbrake not holding, proceed as follows:

1. Conf rm the fault by trying to pull away with the handbrake on.
2. Check the foot brake operation. If correct, this suggests the brake shoes and drums (or pads and discs) are likely to be in good order.
3. Consider this: Do you need to remove the wheels and drums or could it be a cable fault?
4. Check cable operation by using an assistant in the car while you observe.
5. Renew the cable if seized.
6. Check handbrake operation and all associated systems.

7.2.2 Test equipment

7.2.2.1 Brake f uid tester

Because brake f uid can absorb a small amount of water, it must be renewed or tested regularly. It becomes dangerous if the water turns into steam inside the cylinders or pipes, causing the brakes to become ineffective. The tester measures the moisture content of the f uid.

Safety f rst

Note: You should always refer to the manufacturer's instructions appropriate to the equipment you are using.

7.2.2.2 Brake roller test

This is the type of test carried out as part of the annual safety test. The front or rear wheels are driven into a pair of rollers. The rollers drive each wheel of the car and as the brakes are applied the braking force affects the rotation. A measure of braking eff ciency can then be worked out (Figure 7.6).



Figure 7.6 Gauges on a rolling road brake tester



Figure 7.7 Checking for brake disc run out with a dial gauge

7.2.3 Dial gauge

A dial gauge, sometimes called a clock gauge or a dial test indicator (DTI), is used to check the brake disc for run out. The symptoms of this would often be vibration or pulsation when braking. Manufacturers recommend maximum run out f gures. In some cases, the disc can be re-ground but if in any doubt it is often safer and more cost effective to f t new discs. This would also be done in pairs (Figure 7.7).

7.2.4 Test results

Some of the information you may have to get from other sources such as data books or a workshop manual is listed in Table 7.1.

Table 7.1 Tests and information required

Test carried out	Information required
Brake roller test	Required braking eff ciency: 50% for rst-line brakes, 25% for second-line brakes and 16% for the parking brake. On modern vehicles, half of the main system is the second line (dual-line brakes). Old vehicles had to use the parking brake as the second line, therefore it had to work at 25%
Brake fuid condition	Manufacturers specify maximum moisture content

7.2.5 Brakes fault diagnosis table 1

Symptom	Possible faults	Suggested action
Excessive pedal travel	Incorrect adjustment	Adjust it! But check condition as well
Poor performance when stopping	Pad and/or shoe linings worn Seized calliper or wheel cylinders Contaminated linings	Renew Renew or free off, if possible, and safe Renew (both sides)
Car pulls to one side when braking	Seized calliper or wheel cylinder on one side Contaminated linings on one side	Overhaul or renew if piston or cylinder is worn Renew (both sides)
Spongy pedal	Air in the hydraulic system Master cylinder seals failing	Bleed system and then check for leaks Overhaul or renew
Pedal travels to theobr when pressed	Fluid reservoir empty Failed seals in master cylinder Leak from a pipe or union	Refll, bleed system and check for leaks Overhaul or renew Replace or repair as required
Brakes overheating	Shoe return springs broken Callipers or wheel cylinders sticking	Renew (both sides) Free off or renewif in any doubt
Brake judder	Linings worn Drums out of round Discs have excessive run out	Renew Renew Renew
Squeaking	Badly worn linings Dirt in brake drums Anti-squeal shims missing at rear of pads	Renew Clean out with proper cleaner Replace and smear with copper grease

7.2.6 Brakes fault diagnosis table 2

Symptom	Possible cause
Brake fade	Incorrect linings Badly lined shoes Distorted shoes Overloaded vehicle Excessive braking
Spongy pedal	Air in system Badly lined shoes Shoes distorted or incorrectly set Faulty drums Weak master cylinder mounting
Long pedal	Discs running out pushing pads back Distorted damping shims Misplaced dust covers Drum brakes need adjustment Fluid leak Fluid contamination Worn or swollen seals in master cylinder Blocked fller cap vent

(*Continued*)

Symptom	Possible cause
Brakes binding	Brakes or handbrake maladjusted No clearance at master cylinder push rod Seals swollen Seized pistons Shoe springs weak or broken Servo faulty
Hard pedal – poor braking	Incorrect linings Glazed linings Linings wet, greasy or not bedded correctly Servo unit inoperative Seized calliper pistons Worn dampers causing wheel bounce
Brakes pulling	Seized pistons Variation in linings Unsuitable tyres or pressures Loose brakes Greasy linings Faulty drums, suspension or steering
Fall in fluid level	Worn disc pads External leak Leak in servo unit
Disc brake squeal – pad rattle	Worn retaining pins Worn discs No pad damping shims or springs
Uneven or excessive pad wear	Disc corroded or badly scored Incorrect friction material
Brake judder	Excessive disc or drum run out Calliper mounting bolts loose Worn suspension or steering components

7.2.7 Brake hydraulic faults

Brake hose clamps will assist in diagnosing hydraulic faults and enable a fault to be located quickly. Proceed as follows:

1. Clamp all hydraulic flexible hoses and check the pedal.
2. Remove the clamps one at a time and check the pedal again (each time).
3. The location of air in the system or the faulty part of the system will now be apparent.

7.3 Antilock brakes

7.3.1 Introduction

The reason for the development of antilock brakes (ABS) is very simple. Under braking conditions, if one or more of the vehicle wheels lock (begins to skid), then this has a number of consequences:

- braking distance increases;
- steering control is lost;
- tyre wear is abnormal.

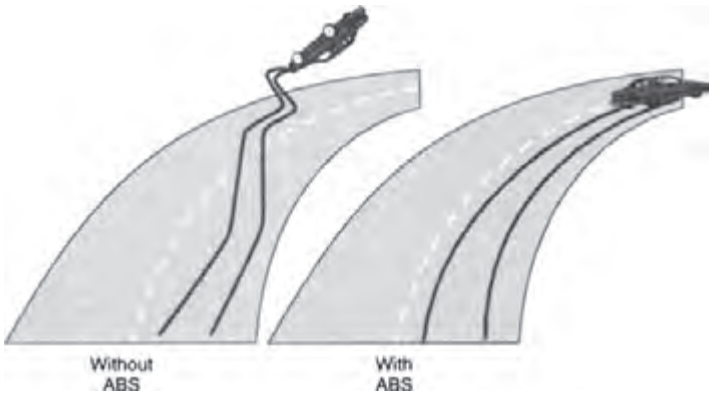


Figure 7.8 Advantages of ABS

The obvious consequence is that an accident is far more likely to occur. The maximum deceleration of a vehicle is achieved when maximum energy conversion is taking place in the brake system. This is the conversion of kinetic energy to heat energy at the discs and brake drums. The potential for this conversion process when a tyre skids, even on a dry road, is far less. A good driver can pump the brakes on and off to prevent locking but electronic control can achieve even better results.

Key fact

The maximum deceleration of a vehicle is achieved when maximum energy conversion is taking place in the brake system – not between the tyres and road.

ABS is becoming more common on lower price vehicles, which should be a contribution to safety. It is important to remember, however, that for normal use, the system is not intended to allow faster driving and shorter braking distances. It should be viewed as operating in an emergency only. Figure 7.8 shows how ABS can help to maintain steering control even under very heavy braking conditions.

7.3.1.1 Requirements of ABS

A good way of considering the operation of a complicated system is to ask, 'What must the system be able to do?' In other words, 'What are the requirements?' These can be considered for ABS under the following headings:

Fail safe system	In the event of the ABS system failing, conventional brakes must still operate to their full potential. In addition, a warning must be given to the driver. This is normally in the form of a simple warning light
Manoeuvrability must be maintained	Good steering and road holding must continue when the ABS system is operating. This is arguably the key issue as being able to swerve round a hazard while still braking hard is often the best course of action
Immediate response must be available	Even over a short distance, the system must react such as to make use of the best grip on the road. The response must be appropriate whether the driver applies the brakes gently or slams them on hard

(*Continued*)

Operational inf uences	Normal driving and manoeuvring should produce no reaction on the brake pedal. The stability and steering must be retained under all road conditions. The system must also adapt to braking hysteresis when the brakes are applied, released and then re-applied. Even if the wheels on one side are on tarmac and the other side on ice, the yaw (rotation about the vertical axis of the vehicle) of the vehicle must be kept to a minimum and only increase slowly to allow the driver to compensate
Controlled wheels	In its basic form, at least one wheel on each side of the vehicle should be controlled on a separate circuit. It is now general for all four wheels to be controlled on passenger vehicles
Speed range of operation	The system must operate under all speed conditions down to walking pace. At this very slow speed, even when the wheels lock, the vehicle will come to rest very quickly If the wheels did not lock, then in theory the vehicle would never stop
Other operating conditions	The system must be able to recognise aquaplaning and react accordingly It must also still operate on an uneven road surface. The one area still not perfected is braking from slow speed on snow The ABS will actually increase stopping distance in snow but steering will be maintained. This is considered to be a suitable trade-off

A number of different types of antilock brake systems are in use, but all operate to achieve the requirements as set out above.

7.3.2 General system description

Key fact

As with many other systems, ABS can be considered as a central control unit with a series of inputs and outputs.

As with other systems, ABS can be considered as a central control unit with a series of inputs and outputs. An ABS system is represented by the closed loop system block diagram shown in Figure 7.9. The most important of the inputs are the wheel speed sensors and the main output is some form of brake system pressure control.

The task of the control unit is to compare signals from each wheel sensor to measure the acceleration or deceleration of an individual wheel. From this data and pre-programmed look-up tables, brake pressure to one or more of the wheels can be regulated. Brake pressure can be reduced, held constant or allowed to increase. The maximum pressure is determined by the driver's pressure on the brake pedal.

From the wheel speed sensors, the electronic control unit (ECU) calculates the components given in Table 7.2.

7.3.3 ABS components

There are a few variations between manufacturers involving a number of different components. For the majority of systems, however, there are three main components.

7.3.3.1 Wheel speed sensors

Most of these devices are simple inductance sensors and work in conjunction with a toothed wheel. They consist of a permanent magnet and a soft iron rod

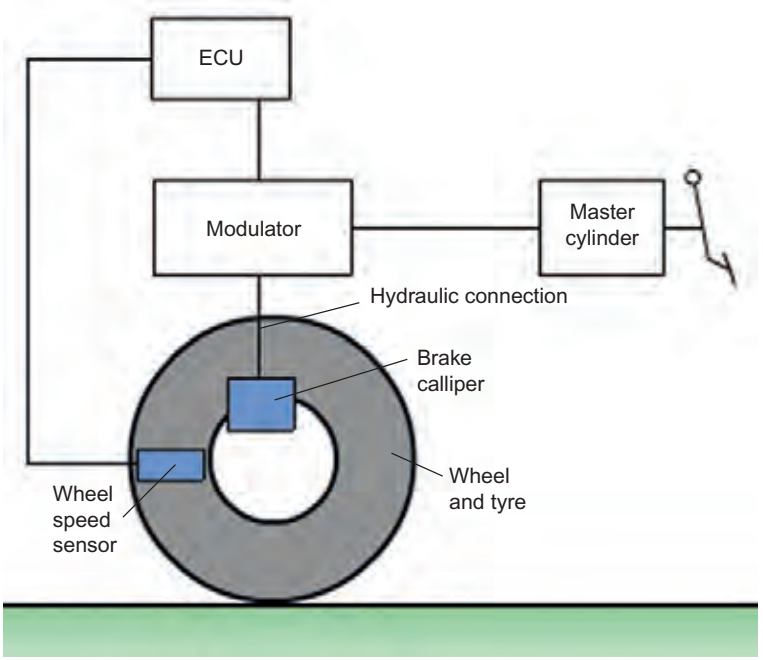


Figure 7.9 ABS closed loop block diagram

Table 7.2 ABS calculations

Vehicle reference speed	Determined from the combination of two diagonal wheel sensor signals. After the start of braking, the ECU uses this value as its reference
Wheel acceleration or deceleration	This is a live measurement that is constantly changing
Brake slip	Although this cannot be measured directly, a value can be calculated from the vehicle reference speed. This figure is then used to determine when/if ABS should take control of the brake pressure
Vehicle deceleration	During brake pressure control, the ECU uses the vehicle reference speed as the starting point and decreases it in a linear manner. The rate of decrease is determined by the evaluation of all signals received from the wheel sensors. Driven and non-driven wheels on the vehicle must be treated in different ways as they behave differently when braking. A logical combination of wheel deceleration/acceleration and slip are used as the controlled variable. The actual strategy used for ABS control varies with the operating conditions

around which is wound a coil of wire. As the toothed wheel rotates, the changes in inductance of the magnetic circuit generates a signal, the frequency and voltage of which are proportional to wheel speed. The frequency is the signal used by the ECU. The coil resistance is in the order of 800–1000 Ω. Coaxial cable is used to prevent interference affecting the signal. Some systems now use 'Hall effect' sensors.

Safety f rst

Note: ABS problems may require specialist attention – but don't be afraid to check the basics. An important note, however is that some systems require special equipment to reinitialise the ECU if it has been disconnected.

7.3.3.2 Electronic control unit

The function of the ECU is to take in information from the wheel sensors and calculate the best course of action for the hydraulic modulator. The heart of a modern ECU consists of two microprocessors such as the Motorola 68HC11, which run the same programme independently of each other. This ensures greater security against any fault which could adversely affect braking performance, because the operation of each processor should be identical. If a fault is detected, the ABS disconnects itself and operates a warning light. Both processors have non-volatile memory into which fault codes can be written for later service and diagnostic access. The ECU also has suitable input signal processing stages and output or driver stages for actuator control.

The ECU performs a self-test after the ignition is switched on. A failure will result in disconnection of the system. The following list forms the self-test procedure:

- current supply;
- exterior and interior interfaces;
- transmission of data;
- communication between the two microprocessors;
- operation of valves and relays;
- operation of fault memory control;
- reading and writing functions of the internal memory.

All this takes less than 300 ms.

7.3.3.3 Hydraulic modulator

A hydraulic modulator has three operating positions:

1. pressure build-up brake line open to the pump;
2. pressure holding brake line closed;
3. pressure release brake line open to the reservoir.

The valves are controlled by electrical solenoids, which have a low inductance so they react very quickly. The motor only runs when ABS is activated. Figure 7.10 shows an ABS hydraulic modulator with integrated ECU.



Figure 7.10 Hydraulic modulators(Source: Bosch Media)

7.4 Diagnostics – antilock brakes

7.4.1 Systematic testing procedure

If the reported fault is the ABS warning light staying on, proceed as given in Figure 7.11 (a scanner may be needed to reset the light).

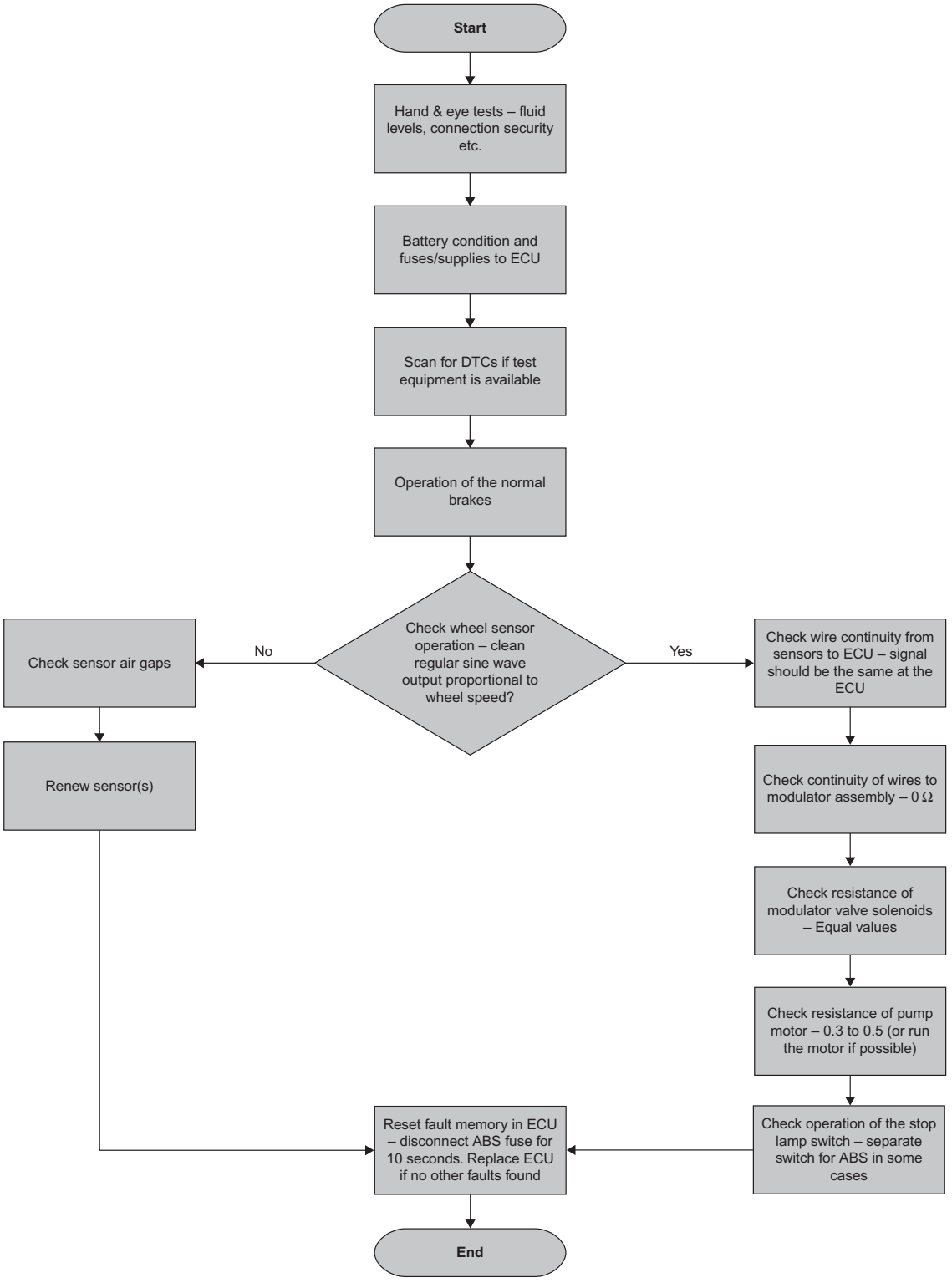


Figure 7.11 ABS diagnosis chart

7.4.2 Antilock brakes fault diagnosis table

Symptom	Possible cause
ABS not working and/or warning light on	Wheel sensor or associated wiring open circuit/high resistance Wheel sensor air gap incorrect Power supply/earth to ECU low or not present Connections to modulator open circuit No supply/earth connection to pump motor Modulator windings open circuit or high resistance
Warning light comes on intermittently	Wheel sensor air gap incorrect Wheel sensor air gap contaminated Loose wire connection

Mercedes Benz C220 2.2 Sport D

ABS diagnostics

Removal/bleeding the system

Speed sensor
- The sensors are protected by tubes which are handed left and right for the vehicle
- Remove safety harness from nearest block connector
- Remove rear road wheel for access to sensor if needed
- Remove brake caliper
- Remove sensor retaining bolt(s) and remove sensor and shims if fitted
- Lightly lubricate sensor sleeve and push in sensor as far as it will go, do not rotate wheel
- Refit sensor retaining bolt and tighten to correct torque
- Check air gap and adjust if needed
- Reconnect harness

Hydraulic control unit
- Disconnect battery
- Remove fluid regulator
- Remove relay cover if fitted
- Remove earth lead
- Remove assistance cable from the centrifugal regulator
- Fit absorbent cloth underneath hydraulic control unit
- Undo hydraulic pipe(s)
- Disconnect retaining nuts/bolts/bracket/mountings
- Remove hydraulic control unit
- Refit in reverse order
- Tighten mounting nuts/bolts to correct torque
- Tighten hydraulic pipes to correct torque
- Bleed system–see bleed instructions

Electronic control unit
- Disconnect battery
- Remove battery, if needed and tray
- Remove seat/trim or mountings for access
- Remove wiring multi-plug/block
- Remove ECU securing screws/bolts or strap
- Remove ECU
- Refit in reverse order

G or acceleration sensor
- This operation only applies to four wheel drive models
- Disconnect electrical connections
- Drill out mounting bolts
- Remove mounting bolts/nuts and remove unit
- Fit unit with arrow pointing in direction of vehicle movement

Bleeding the brakes
- Do not switch on ignition before bleeding the system as this could cause air bubbles to form in the hydraulic unit
- Bleed system without the aid of the servo, on a level surface and without the wheels suspended
- If the hydraulic control unit is fitted with bleed screw(s), bleed these first in the conventional manner. Bleed screw first then second bleed screw (if fitted with two bleed screws)
- Cars fitted with delay valve must be bled before the remainder of the system
- To bleed delay valve release screw (below bleed screw) one turn
- Pump pedal 10 times and hold pressure
- Open bleed screw and close before pressure is completely lost
- For cars with diagonally split systems bleed each system in turn starting with right rear, left front, left rear, right front
- For cars with front/rear split systems bleed rear first then front
- Fill fluid reservoir
- Check operation of warning lights
- Low speed road tests and check ABS operation

Figure 7.12 ABS repair process example

7.4.3 Bleeding antilock brakes

Special procedures may be required to bleed the hydraulic system when ABS is f tted. Refer to appropriate data for the particular vehicle. An example is reproduced in Figure 7.12.

7.5 Traction control

7.5.1 Introduction

The steerability of a vehicle is not only lost when the wheels lock up on braking, the same effect arises if the wheels spin when driving off under severe acceleration. Electronic traction control has been developed as a supplement to ABS. This control system prevents the wheels from spinning when moving off or when accelerating sharply while on the move. In this way, an individual wheel which is spinning is braked in a controlled manner. If both or all of the wheels are spinning, the drive torque is reduced by means of an engine control function. Traction control has become known as traction control system (TCS), anti-slip regulation (ASR), or just traction control (TCR).

Key fact

Traction control is usually combined with ABS.

Traction control is not normally available as an independent system but in combination with ABS. This is because many of the components required are the same as for the ABS. Traction control only requires a change in logic control in the ECU and a few extra control elements such as control of the throttle. Figure 7.13 shows a block diagram of a traction control system. Note the links with ABS and the engine control system.

Traction control will intervene to

- maintain stability;
- reduce yawing moment reactions;
- provide optimum propulsion at all speeds;
- reduce driver workload.

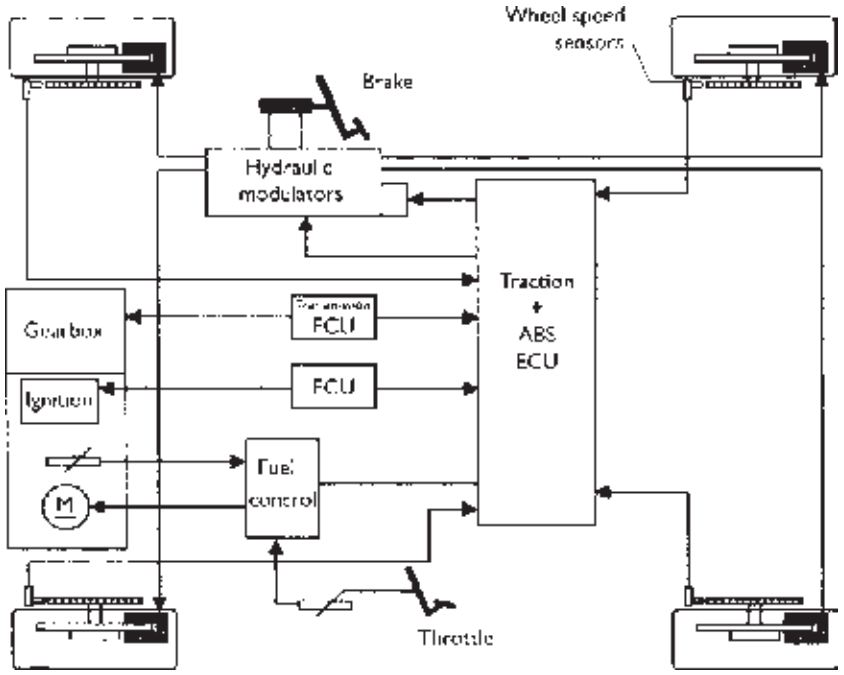


Figure 7.13 Integrated traction control system

An automatic control system can intervene in many cases more quickly and precisely than the driver of the vehicle. This allows stability to be maintained at a time when the driver might not have been able to cope with the situation.

7.5.2 Control functions

Control of tractive force can be by a number of methods.

Throttle control	This can be via an actuator which can move the throttle cable, or if the vehicle employs a drive by wire accelerator then control will be in conjunction with the engine management ECU. This throttle control will be independent of the drivers throttle pedal position. This method alone is relatively slow to control engine torque
Ignition control	If ignition is retarded, the engine torque can be reduced by up to 50% in a very short space of time. The timing is adjusted by a set ramp from the ignition map value
Braking effect	If the spinning wheel is restricted by brake pressure, the reduction in torque at the affected wheel is very fast. Maximum brake pressure is not used to ensure that passenger comfort is maintained

7.5.3 System operation

The description that follows is for a vehicle with an electronic accelerator (drive by wire). A simple sensor determines the position of the accelerator and, taking into account other variables such as engine temperature and speed for example, the throttle is set at the optimum position by a servomotor. When accelerating, the increase in engine torque leads to an increase in driving torque at the wheels. To achieve optimum acceleration, the maximum possible driving torque must be transferred to the road. If driving torque exceeds that which can be transferred then wheel slip will occur on at least one wheel. The result of this is that the vehicle becomes unstable.

When wheel spin is detected, the throttle position and ignition timing are adjusted, but the best results are gained when the brakes are applied to the spinning wheel. This not only prevents the wheel from spinning but acts to provide a limited slip differential action. This is particularly good when on a road with varying braking force coeff cients. When the brakes are applied, a valve in the hydraulic modulator assembly moves over to allow traction control operation. This allows pressure from the pump to be applied to the brakes on the offending wheel. The valves, in the same way as with ABS, can provide pressure build-up, pressure hold and pressure reduction. All these take place without the driver touching the brake pedal. The summary of this is that the braking force must be applied to the slipping wheel so as to equalise the combined braking coeff cient for each driving wheel.

Safety f rst

Note: Traction control (TCR or TCS or ASC) is usually linked with the ABS and problems may require specialist attention – but don't be afraid to check the basics. As with ABS, note that some systems require special equipment to reinitialise the ECU if it has been disconnected.

7.6 Diagnostics – traction control

7.6.1 Systematic testing

If the reported fault is the traction control system not working, proceed as given in Figure 7.14.

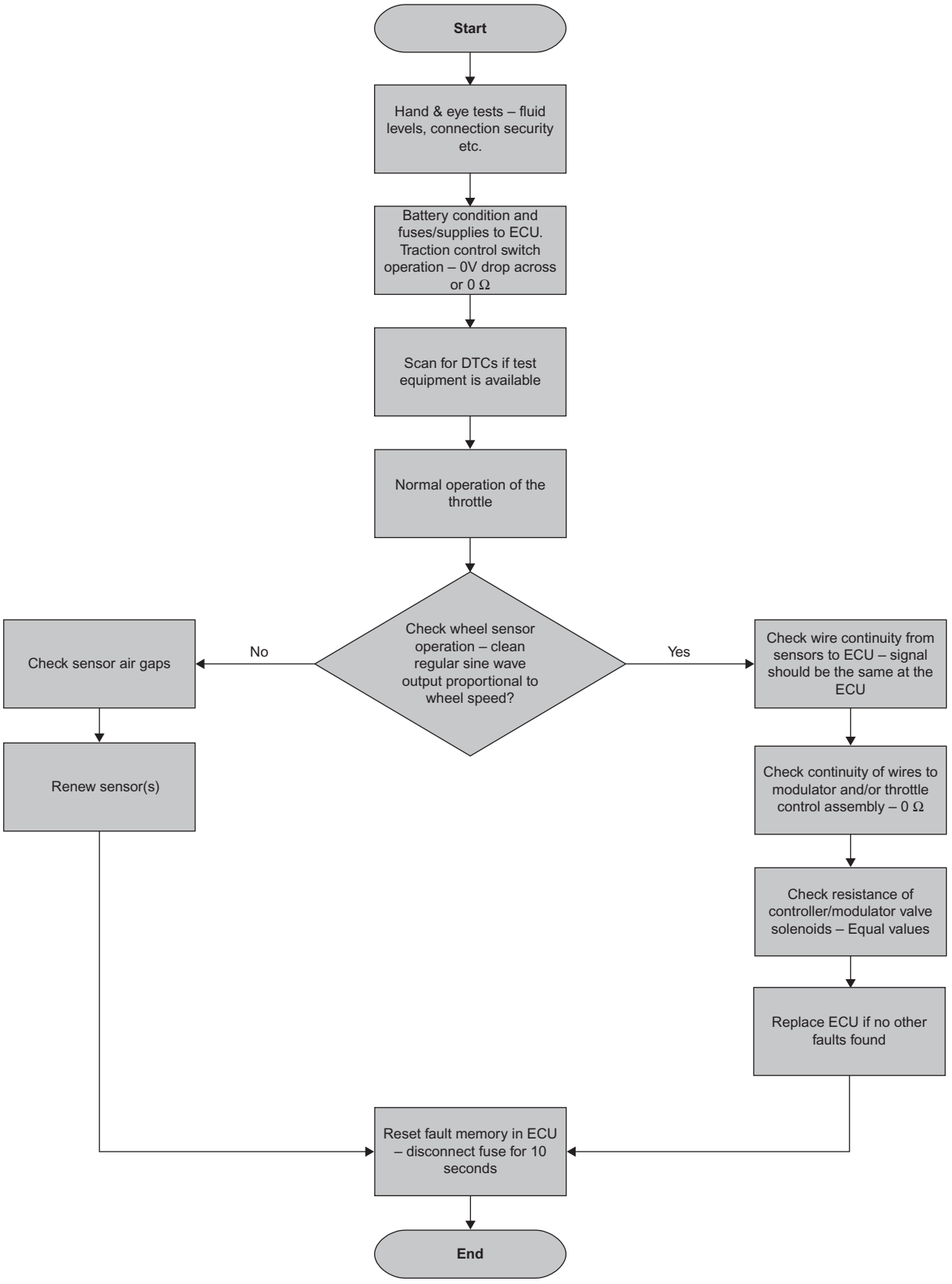


Figure 7.14 Traction control diagnosis chart

7.6.2 Traction control fault diagnosis table

Symptom	Possible cause
Traction control inoperative	Wheel sensor or associated wiring open circuit/high resistance Wheel sensor air gap incorrect Power supply/earth to ECU low or not present Switch open circuit ABS system fault Throttle actuator inoperative or open circuit connections Communication link between ECUs open circuit ECU needs to be initialised

7.7 Steering and tyres

The tyre performs two basic functions:

1. It acts as the primary suspension, cushioning the vehicle from the effects of a rough surface.
2. It provides frictional contact with the road surface. This allows the driving wheels to move the vehicle. The tyres also allow the front wheels to steer and the brakes to slow or stop the vehicle.

Key fact

Modern tyres are almost always tubeless.

The tyre is a f exible casing which contains air. Tyres are manufactured from reinforced synthetic rubber. The tyre is made of an inner layer of fabric plies which are wrapped around bead wires at the inner edges. The bead wires hold the tyre in position on the wheel rim. The fabric plies are coated with rubber, which is moulded to form the side walls and the tread of the tyre. Behind the tread is a reinforcing band, usually made of steel, rayon or glass f bre. Modern tyres are mostly tubeless, so they have a thin layer of rubber coating the inside to act as a seal.

7.7.1 Construction of a tubeless radial tyre

The wheel is made with a leak-proof rim and the valve is rubber mounted into a hole formed in the well of the rim. The tyre is made with an accurate bead, which f ts tightly onto the rim. A thin rubber layer in the interior of the tyre makes an airtight seal.

Key fact

The plies of a radial tyre pass from bead to bead at 90° to the circumference, or radially

The plies of a radial tyre pass from bead to bead at 90° to the circumference, or radially. There is a rigid belt band consisting of several layers of textile or metallic threads running round the tyre under the tread. Steel wire is often used in the construction of radial tyres. The radial tyre is f exible but retains high strength. It has good road holding and cornering power. In addition, radial tyres are economical due to their low ‘rolling resistance’ (Figure 7.15).

A major advantage of a radial tyre is its greatly improved grip even on wet roads. This is because the rigid belt band holds the tread f at on the road surface, when cornering. The rigid belt band also helps with the escape of water from under the tyre.

7.7.2 Steering box and rack

Steering boxes contain a spiral gear known as a worm gear, or something similar, which rotates with the steering column. One form of design has a nut wrapped



Figure 7.15 Tyres

round the spiral and is therefore known as a worm and nut-steering box. The grooves can be f lled with recirculating ball bearings, which reduce backlash or slack in the system and also reduce friction, making steering lighter. On vehicles with independent front suspension, an idler unit is needed together with a number of links and several joints. The basic weakness of the steering box system is in the number of swivelling joints and connections. If there is just slight wear at a number of points, the steering will not feel, or be, positive.

The steering rack is now used almost without exception on light vehicles. This is because it is simple in design and very long lasting. The wheels turn on two large swivel joints. Another ball joint (often called a track rod end) is f tted on each swivel arm. A further ball joint to the ends of the rack connects the track rods. The rack is inside a lubricated tube and gaiters protect the inner ball joints. The pinion meshes with the teeth of the rack, and as it is turned by the steering wheel, the rack is made to move back and forth, turning the front wheels on their swivel ball joints. On many vehicles now, the steering rack is augmented with hydraulic power assistance (Figure 7.16).

Key fact

The steering rack is now used on almost all light vehicles because it is simple in design, long lasting and makes optimum use of available space.

7.7.3 Power-assisted steering

Rack and pinion steering requires more turning effort than a steering box, although this is not too noticeable with smaller vehicles. However, most cars, in particular heavier ones with larger engines or with wider tyres, which scrub more, often benef t from power steering.

Many vehicles use a belt-driven hydraulic pump to supply f uid under pressure for use in the system. Inside the rack and pinion housing is a hydraulic valve, which is operated as the pinion is turned for steering. The valve controls the f ow of oil into a cylinder, which has a piston connected to the rack. This assists with the steering effort quite considerably.

A well-designed system will retain ‘feel’ of road conditions for the driver to control the car. Steering a slow-moving heavier vehicle when there is little room can be tiring or even impossible for some drivers. This is where power steering has its best advantage. Many modern systems are able to make the power steering

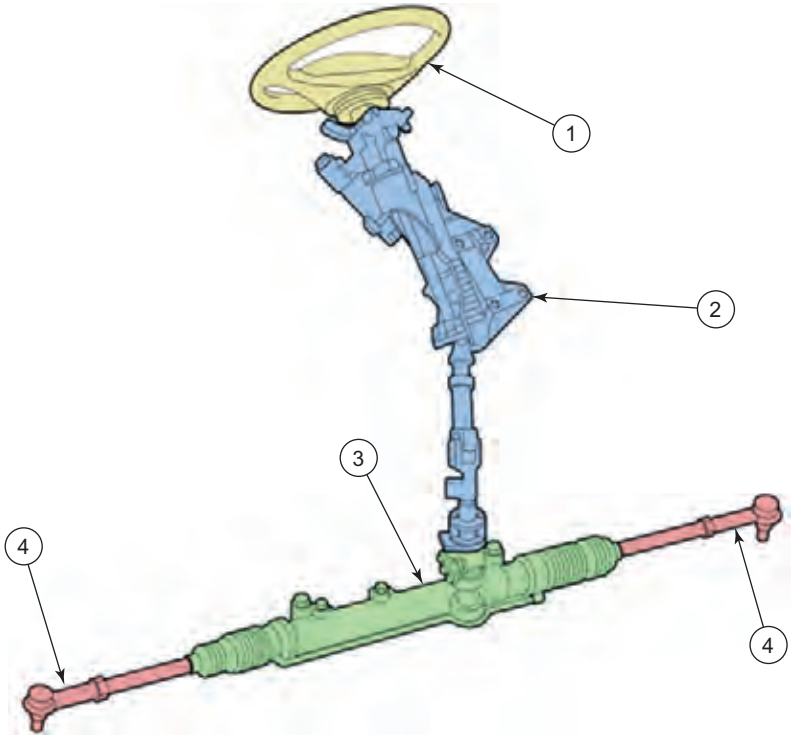


Figure 7.16 Steering system: 1 – steering wheel; 2 – column; 3 – rack; 4 – track rod ends



Figure 7.17 Electric power steering (Source: ZF)

progressive. This means that as the speed of the vehicle increases, the assistance provided by the power steering reduces. This maintains better driver feel.

Many modern systems use electric power steering. This employs a powerful electric motor as part of the steering linkage. There are two main types of electric power steering:

- replacing the conventional hydraulic pump with an electric motor while the ram remains much the same;
- a drive motor, which directly assists with the steering and which has no hydraulic components (the most common method now).

The second system uses a small electric motor acting directly on the steering via an epicyclic gear train. This completely replaces the hydraulic pump and servo cylinder. It also eliminates the fuel penalty of the conventional pump and greatly simplif es the drive arrangements. Engine stall when the power steering is operated at idle speed is also eliminated.

An optical torque sensor is used to measure driver effort on the steering wheel. The sensor works by measuring light from an LED which is shining through holes that are aligned in discs at either end of a 50 mm torsion bar f tted into the steering column. Other methods are also used, but the optical is most common (Figure 7.17).

Key fact

Many modern systems use electric power steering.

7.7.4 Steering characteristics

The steering characteristics of a vehicle, or in other words, the way in which it reacts when cornering, can be described by one of three headings:

1 oversteer;
2 understeer;
3 neutral.

Oversteer occurs when the rear of the vehicle tends to swing outward more than the front during cornering. This is because the slip angle on the rear axle is significantly greater than the front axle. This causes the vehicle to travel in a tighter circle, hence the term oversteer. If the steering angle is not reduced, the vehicle will break away and all control will be lost. Turning the steering towards the opposite lock will reduce the front slip angle.

Understeer occurs when the front of the vehicle tends to swing outward more than the rear during cornering. This is because the slip angle on the rear axle is signif cantly smaller than the front axle. This causes the vehicle to travel in a greater circle, hence the term understeer. If the steering angle is not increased, the vehicle will be carried out of the corner and all control will be lost. Turning the steering further into the bend will increase the front slip angle. Front-engined vehicles tend to understeer because the centre of gravity is situated in front of the vehicle centre. The outward centrifugal force therefore has a greater effect on the front wheels than on the rear.

Neutral steering occurs when the centre of gravity is at the vehicle centre and the front and rear slip angles are equal. The cornering forces are therefore uniformly spread. Note, however, that understeer or oversteer can still occur if the cornering conditions change.



Figure 7.18 Positive camber

7.7.5 Camber

On many cars, the front wheels are not mounted vertically to the road surface. Often they are tilted outwards at the top. This is called positive camber (Figure 7.18), and has the following effects:

- easier steering, less turning effort required;
- less wear on the steering linkages;
- less stress on main components;
- smaller scrub radius, which reduces the effect of wheel forces on the steering.

Negative camber has the effect of giving good cornering force (Figure 7.19). Some cars have rear wheels with negative camber. With independent suspension systems, wheels can change their camber from positive through neutral to negative as the suspension is compressed. This varies, however, with the design and position of the suspension hinge points.



Figure 7.19 Negative camber

7.7.6 Castor

The front wheels tend to straighten themselves out after cornering. This is due to a castor action. Supermarket trolley wheels automatically run straight when pushed because the axle on which they rotate is behind the swivel mounting. Vehicle wheels get the same result by leaning the swivel pin mountings back so that the wheel axle is moved slightly behind the line of the swivel axis. The further the axle is behind the swivel, the stronger will be the straightening effect. The main effects of a positive castor angle (Figure 7.20) are

- self-centring action;
- helping in determining the steering torque when cornering.

Key fact

Typical value for camber is approximately 0.5° (values will var so check specs).

Key fact

Typical castor value is approximately 2–4° (values will vary so check specs)

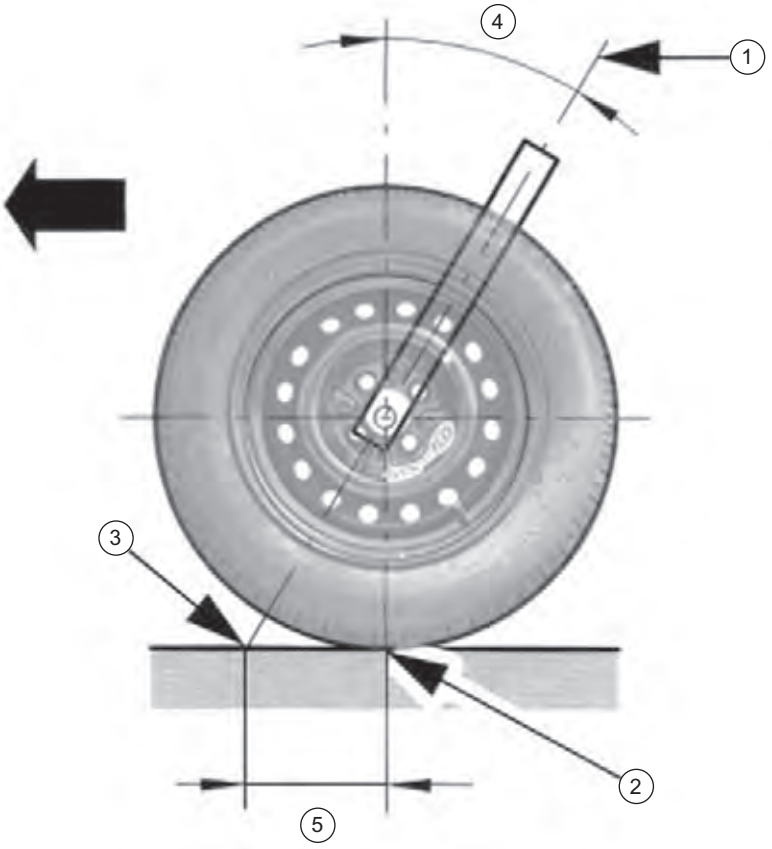


Figure 7.20 Castor angle – Positive: 1 – steering axis; 2 – wheel contact point; 3 – positive castor point of intersection of steering axis with the road surface; 4 – castor angle

Negative castor is used on some front wheel drive vehicles to reduce the return forces when cornering (Figure 7.21). Note that a combination of steering geometry angles is used to achieve the desired effect. This means that in some cases the swivel axis produces the desired self-centre action so the castor angle may need to be negative to reduce the return forces on corners.

7.7.7 Swivel axis inclination

Def nition

SAI: Swivel axis inclination

KPI: King pin inclination

The swivel axis is also known as the steering axis. Swivel axis inclination (Figure 7.22) means the angle compared to vertical made by the two swivel joints when viewed from the front or rear. On a strut-type suspension system, the angle is broadly that made by the strut. This angle always leans towards the middle of the vehicle. The swivel axis inclination (also called kingpin inclination) is mainly for

- producing a self-centre action;
- improving steering control on corners;
- giving a lighter steering action.

Key fact

Typical KPI/SAI value is approximately 7–9° (values will vary so check specs)

Scrub radius, wheel camber and swivel axis inclination, all have an effect on one another. The swivel axis inclination mainly affects the self-centring action, also known as the aligning torque. Because of the axis inclination, the vehicle is raised slightly at the front as the wheels are turned. The weight of the vehicle therefore tries to force the wheels back into the straight-ahead position.

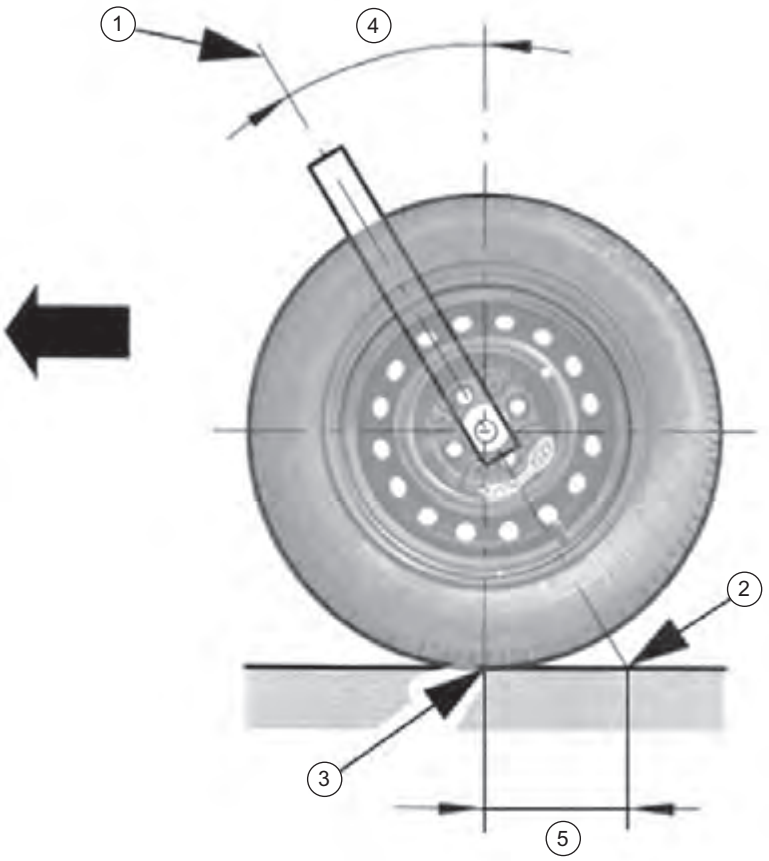


Figure 7.21 Castor angle – Negative: 1 – steering axis; 2 – wheel contact point; 3 – negativ castor point of intersection of steering axis with the road surface; 4 – castor angle

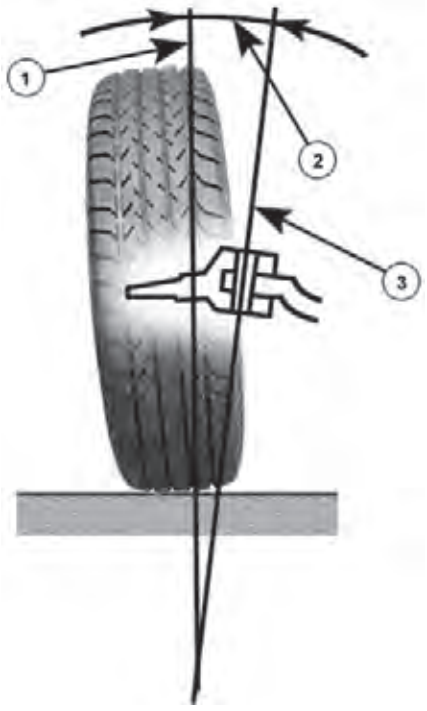


Figure 7.22 King pin or swivel axis inclination: 1 – perpendicular; 2 – swivel angle; 3 – steering axis

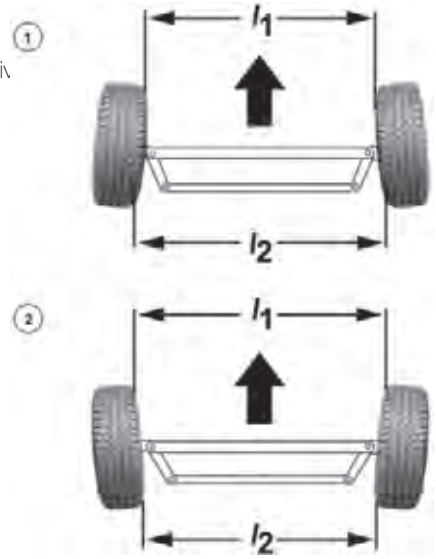


Figure 7.23 Tracking: 1 – toe-in; 2 – toe-out

7.7.8 Tracking

As a front wheel drive car drives forward, the tyres pull on the road surface, taking up the small amount of free play in the mountings and joints. For this reason, the tracking is often set toe-out so that the wheels point straight ahead when the vehicle is moving. Rear wheel drive tends to make the opposite happen because it pushes against the front wheels. The front wheels are therefore set toe-in. When the car moves, the front wheels are pushed out taking up the slack in the joints, so the wheels again end up straight ahead. The amount of toe-in or toe-out is very small, normally not exceeding 5 mm (the difference in the distance between the front and rear of the front wheels). Correctly set tracking ensures true rolling of the wheels and therefore reduced tyre wear. Figure 7.23 shows wheels set toe-in and toe-out.

7.7.9 Scrub radius

The scrub radius is the distance between the contact point of the steering axis with the road and the wheel centre contact point. The purpose of designing in a scrub radius is to reduce the steering force and to prevent steering shimmy. It also helps to stabilise the straight-ahead position. It is

Key fact

As a front wheel drive car drives forward, the tyres pull on the road surface, forcing the toe-out of the wheels inwards – resulting in them being parallel (but check data).

Table 7.3 Scrub radius

Scrub radius	Description	Properties
Negative	The contact point of the steering axis hits the road between the wheel cent and the outer edge of the wheel	Braking forces produce a torque which tends to make the wheel eturn inwards. The result of this is that the wheel with the greatest braking force is turned in with greater torque. This steers the vehicle away from the side with the heaviest braking producing a built-in counter steer action which has a stabilising effect
Positive	The contact point of the steering axis hits the road between the wheel cent and the inner edge of the wheel	A positive scrub radius makes turning the steering easier eHowever, braking forces produce a torque, which tends to make the wheel turn outwards. The result of this is that the wheel with the greatest braking force is turned out with greater torque. Under different road conditions, this can have the effect of producing an unwanted steering angle
Zero	The contact point of the steering axis hits the road at the same place as t wheel centre	This makes the steering heavy when the vehicle is at rest ebecause the wheel cannot roll at the steering angle. However no separate turning torque about the steering axis is created

Key fact

The scrub radius is the distance between the contact point of the steering axis with the road and the wheel centre contact point.

possible to design the steering with a negative, positive or zero scrub radius as described in Table 7.3.

From the information given, you will realise that decisions about steering geometry are not clear-cut. One change may have a particular advantage in one area but a disadvantage in another. To assist with fault diagnosis, a good understanding of steering geometry is essential.

7.8 Diagnostics – steering and tyres

7.8.1 Systematic testing

If the reported fault is heavy steering, proceed as follows:

1. Ask if the problem has just developed. Road test to conf rm.
2. Check the obvious such as tyre pressures. Is the vehicle loaded to excess? Check geometry?
3. Assuming tyre pressure and condition is as it should be, we must move on to further tests.
4. For example, jack up and support the front of the car. Operate the steering lock to lock. Disconnect one track rod end and move the wheel on that side, and so on.
5. If the fault is in the steering rack, then this should be replaced and the tracking should be set.
6. Test the operation with a road test and inspect all other related components for security and safety.

Safety f rst

Note: You should always refer to the manufacturer's instructions appropriate to the equipment you are using.

7.8.2 Test equipment

7.8.2.1 Tyre pressure gauge and tread depth gauge

These are often underrated pieces of test equipment. Correctly inf ated tyres make the vehicle handle better, stop better and use less fuel. The correct depth



Figure 7.24 Basic mirrortype tracking gauges

of tread means the vehicle will be signif cantly safer to drive, particularly in wet conditions.

7.8.2.2 Tracking gauges

The toe-in and toe-out of a vehicle's front wheels are very important. Many types of tracking gauges are available. One of the most commonly used is a frame placed against each wheel with a mirror on one side and a moveable viewer on the other (Figure 7.24). The viewer is moved until marks are lined up and the tracking can then be measured.

7.8.2.3 Wheel balancer

This is a large f xed piece of equipment in most cases. The wheel is removed from the car, f xed onto the machine and spun at high speed. Sensors in the tester measure the balance of the wheel. The tester then indicates the amount of weight which should be added to a certain position. The weight is added by f tting small lead weights (Figure 7.25).

7.8.3 Four-wheel alignment

Standard front-wheel alignment is simply a way of making sure the wheels are operating parallel with one another and that the tyres meet the road at the correct angle. Four-wheel alignment makes sure that the rear wheels follow the front wheels in a parallel path.

Different manufacturers set different specif cations for the angles created between the suspension, steering, wheels and the frame of the vehicle. When these angles are correct, the vehicle is properly aligned.

The main reasons for correct alignment are to ensure that the vehicle achieves

- minimum rolling friction;
- maximum tyre mileage;
- stability on the road;
- steering control for the driver.



Figure 7.25 Wheel balancer



Figure 7.26 Laser alignment systems give digital readouts

Diagnosing incorrect alignments is usually just a matter of examining the

- tyres for unusual wear;
- wheels for damage;
- steering wheel for position.

In addition, a road test is usually necessary to check that the vehicle is not pulling to one side, wandering or weaving. Four basic wheel settings or angles determine whether a vehicle is properly aligned (Figures 7.26 and 7.27).

- Camber is the inward or outward tilt of a wheel compared to a vertical line. If the camber is out of adjustment, it will cause tyre wear on one side of the tyre's tread.



Figure 7.27 Scale to show angle of wheels

Table 7.4 Tests and information required

Test carried out	Information required
Tracking	The data for tracking will be given as either an angle or a distance measurement. Ensure you use the appropriate data for your type of test equipment. The distance will be a figure such as 3 mm toe-in, and if as an angle such as 50' toe-in (50' means 50 minutes). The angle of 1° is split into 60 minutes, so in this case the angle is 50/60 or 5/6 of a degree
Pressures	A simple measurement which should be in bars. You will find, however, many places still use PSI (pounds per square inch). As in all other cases, only compare like with like
Tread depth	The minimum measurement (e.g. 1.6 mm over 75% of the tread area but please note the current local legal requirements)

- Caster is the degree that the car's steering axis is tilted forward or backward from the vertical as viewed from the side of the car. If the caster is out of adjustment, it can cause problems with self-centring and wander. Caster has little effect on tyre wear.
- Toe refers to the directions in which two wheels point relative to each other. Incorrect toe causes rapid tyre wear to both tyres equally. Toe is the most common adjustment and it is always adjustable on the front wheels and is adjustable on the rear wheels of some cars.

7.8.4 Test results

Some of the information you may have to get from other sources such as data books or a workshop manual is listed in Table 7.4.

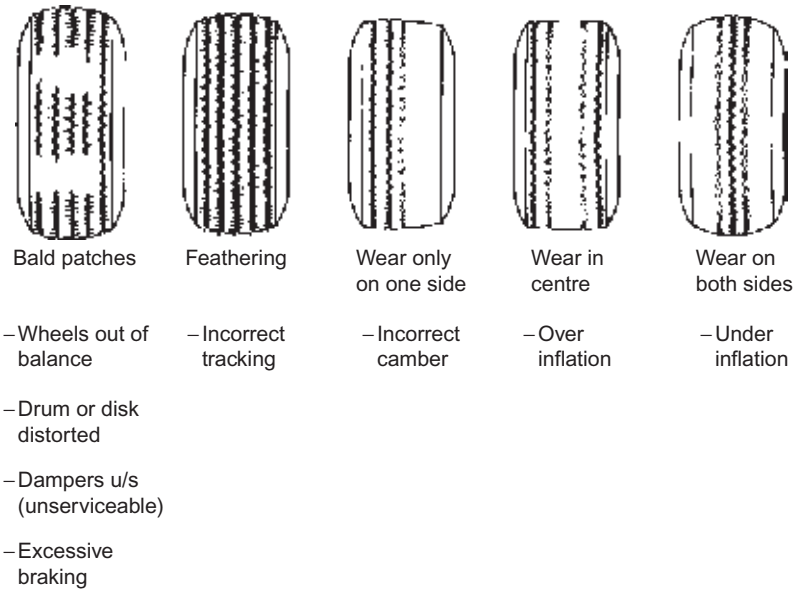


Figure 7.28 Tread wear patterns are a useful diagnostic aid

7.8.5 Tyres fault diagnosis table

The following table lists some of the faults which can occur if tyres and/or the vehicle are not maintained correctly. Figure 7.28 shows the same.

Symptom	Possible cause/fault
Wear on both outer edges of the tread	Under inflation
Wear in the centre of the tread all round the tyre	Over inflation
Wear just on one side of the tread	Incorrect camber
Feathering	Tracking not set correctly
Bald patches	Unbalanced wheels or unusual driving technique!

7.8.6 Tyre inflation pressures

The pressure at which the tyres should be set is determined by a number of factors such as

- load to be carried;
- number of plies;
- operating conditions;
- section of the tyre.

Tyre pressures must be set at the values recommended by the manufacturers. Pressure will vary according to the temperature of the tyre – this is affected by operating conditions. Tyre pressure should always be adjusted when the tyre is cold and be checked at regular intervals.

Safety first

Tyre pressures must always be set at the values recommended by the manufacturer.

7.8.7 Steering fault diagnosis table 1

Symptom	Possible faults	Suggested action
Excessive free play at steering wheel	Play between the rack and pinion or in the steering box Ball joints or tie-rod joints worn Column coupling loose or bushes worn	Renew in most cases but adjustment may be possible Renew Secure or renew
Vehicle wanders, hard to keep in a straight line	As above Alignment incorrect Incorrect tyre pressure or mix of tyre types is not suitabl Worn wheel bearings	As above Adjust to recommended setting Adjust pressures or replace tyres as required Renew
Stiff steering	Wheel alignment incorrect Tyre pressures too low Ball joints or rack seizing	Adjust to recommended setting Adjust pressures Renew
Wheel wobble	Wheels out of balance Wear in suspension linkages Alignment incorrect	Balance or renew Renew Adjust to recommended setting
Under steer or over steer	Tyre pressures incorrect Dangerous mix of tyre types Excessive free play in suspension or steering system	Adjust pressures Replace tyres as required Renew components as required

7.8.8 Steering, wheels and tyres fault diagnosis

Symptom	Possible cause
Wandering or instability	Incorrect wheel alignment Worn steering joints Wheels out of balance Wheel nuts or bolts loose
Wheel wobble	Front or rear Wheels out of balance Damaged or distorted wheels/tyres Worn steering joints
Pulling to one side	Defective tyre Excessively worn components Incorrect wheel alignment
Excessive tyre wear	Incorrect wheel alignment Worn steering joints Wheels out of balance Incorrect infation pressures Driving style! Worn dampers
Excessive free-play	Worn track rod end or swivel joints Steering column bushes worn Steering column universal joint worn
Stiff steering	Lack of steering gear lubrication Seized track rod end joint or suspension swivel joint Incorrect wheel alignment Damage to steering components

7.9 Suspension

7.9.1 Introduction

The purpose of a suspension system can best be summarised by the following requirements:

- cushion the car, passengers and load from road surface irregularities;
- resist the effects of steering, braking and acceleration, even on hills and when loads are carried;
- keep tyres in contact with the road at all times;
- work in conjunction with the tyres and seat springs to give an acceptable ride at all speeds.

The above list is diff cult to achieve completely, so some sort of compromise has to be reached. Because of this, many different methods have been tried, and many are still in use. Keep these four main requirements in mind and it will help you understand why some systems are constructed in different ways.

Key fact

A suspension system reduces road shocks so providing comfort to the passengers and preventing damage to the load and vehicle components.

A vehicle needs a suspension system to cushion and damp out road shocks so providing comfort to the passengers and preventing damage to the load and vehicle components. A spring between the wheel and the vehicle body allows the wheel to follow the road surface. The tyre plays an important role in absorbing small road shocks. It is often described as the primary form of suspension. The vehicle body is supported by springs located between the body and the wheel axles. Together with the damper, these components are referred to as the suspension system.

As a wheel hits a bump in the road, it is moved upwards with quite some force. An unsprung wheel is affected only by gravity, which will try to return the wheel to the road surface but most of the energy will be transferred to the body. When a spring is used between the wheel and the vehicle body, most of the energy in the bouncing wheel is stored in the spring and not passed to the vehicle body. The vehicle body will now only move upwards through a very small distance compared to the movement of the wheel.

7.9.2 Suspension system layouts

On older types of vehicle, a beam axle was used to support two stub axles. Beam axles are now rarely used in car suspension systems, although many commercial vehicles use them because of their greater strength and constant ground clearance (Figure 7.29).

The need for a better suspension system came from the demand for improved ride quality and improved handling (Figure 7.30). Independent front suspension (IFS) was developed to meet this need. The main advantages of independent front suspension are as follows:

- When one wheel is lifted or drops, it does not affect the opposite wheel.
- The unsprung mass is lower, therefore the road wheel stays in better contact with the road.
- Problems with changing steering geometry are reduced.

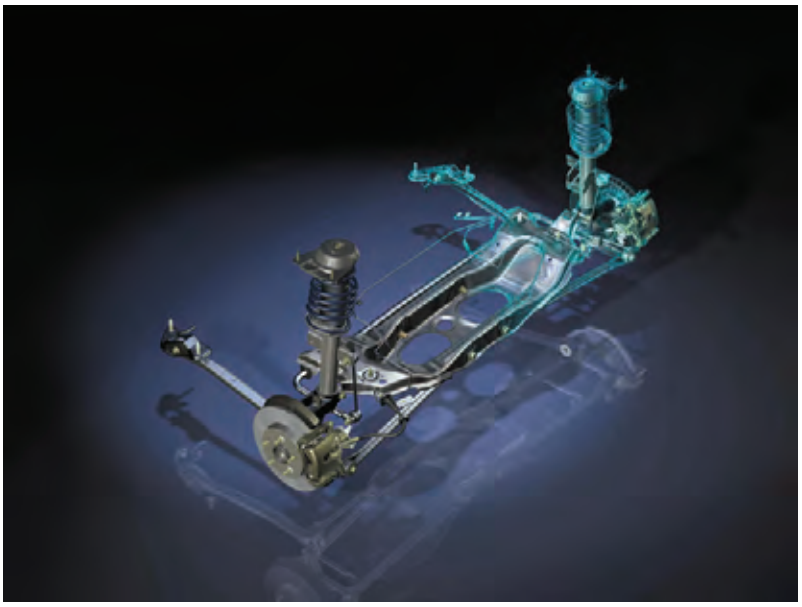


Figure 7.29 Rear suspension layout(Source: Ford Media)

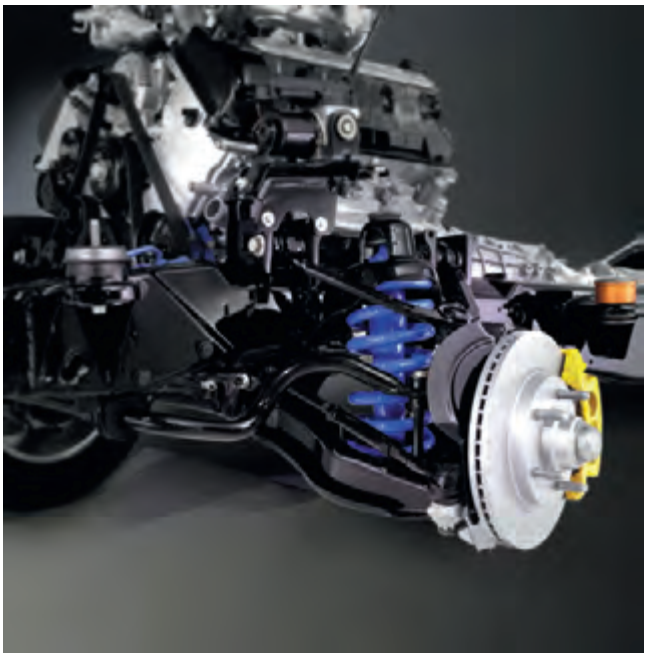


Figure 7.30 Front wishbone suspension system

- There is more space for the engine at the front.
- Softer springing with larger wheel movement is possible.

There are a number of basic suspension systems in common use. Figure 7.31 shows a front suspension layout on a Jaguar.

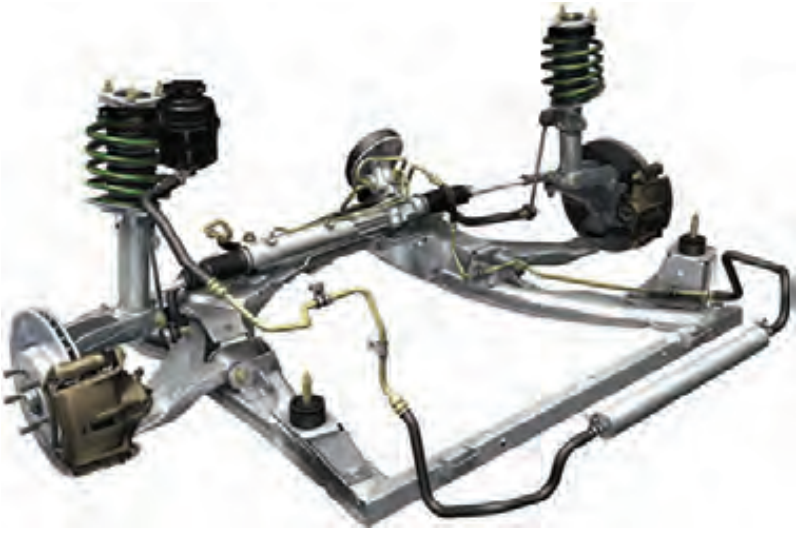


Figure 7.31 Front suspension struts (Source: Jaguar Media)

Table 7.5 Front axle suspension

Name	Description	Advantages	Disadvantages
Double transverse arms	Independently suspended wheels located by two arms perpendicular to direction of travel. The arms support stub axles	Low bonnet line Only slight changes of track and camber with suspension movements	A large number of pivot points is required High production costs
Transverse arms with leaf spring	A traverse arm and a leaf spring locate the wheel	The spring can act as an anti-roll bar, hence low cost	Harsh response when lightly loaded Major changes of camber as vehicle is loaded
Transverse arm with McPherson strut	A combination of the spring, damper, wheel hub, steering arm and axle joints in one unit	Only slight changes in track and camber with suspension movement Forces on the joints are reduced because of the long strut	The body must be strengthened around the upper mounting A low bonnet line is difficult to achieve
Double trailing arms	Two trailing arms support the stub axle. These can act on torsion bars often formed as a single assembly	No change in castor, camber or track with suspension movement Can be assembled and adjusted off the vehicle	Lots of space is required at the front of the vehicle Expensive to produce Acceleration and braking cause pitching movements which in turn changes the wheel base

7.9.3 Front axle suspensions

As with most design aspects of the vehicle, compromise often has to be reached between performance, body styling and cost. Table 7.5 compares the common front axle suspension systems.

Table 7.6 Rear axle suspension

Name	Description	Advantages	Disadvantages
Rigid axle with leaf springs	The final drive, differential and axle shafts are all one unit	Rear track remains constant, reducing tyre wear Good directional stability because no camber change causes body roll on corners Low cost Strong design for load carrying	High unsprung mass The interaction of the wheels causes lateral movement. reducing tyre adhesion when the suspension is compressed on one side
Rigid axle with A-bracket	Solid axle with coil springs and a central joint supports the axle on the body	Rear of the vehicle pulls down on braking which stabilises the vehicle	High cost Large unsprung mass
Rigid axle with compression/tension struts	Coil springs provide the springing and the axle is located by struts	Suspension extension is reduced when braking or accelerating The springs are isolated from these forces	High loads on the welded joints High weight overall Large unsprung mass
Torsion beam trailing arm axle	Two links are used, connected by a 'U' section that has low torsional stiffness but high resistance to bending	Track and camber does not change Low unsprung mass Simple to produce Space saving	Torsion bar springing on this system can be more expensive than coil springs
Torsion beam axle with Panhard rod	Two links are welded to an axle tube or 'U' section and lateral forces are taken by a Panhard rod	Track and camber do not change Simple flexible joints to the bodywork	Torsion bar springing on this system can be more expensive than coil springs
Trailing arms	The pivot axis of the trailing arms is at 90° to the direction of vehicle travel	When braking, the rear of the vehicle pulls down, giving stable handling Track and camber do not change Space saving	Slight change of wheel base when the suspension is compressed
Semi-trailing arms – fixed-lengthdrive shafts	The trailing arms are pivoted at an angle to the direction of travel. Only one universal joint (UJ) is required because the radius of the suspension arm is the same as the driveshaft when the suspension is compressed	Only very small dive when braking Lower cost than when variable length shafts are used	Sharp changes in track when the suspension is compressed resulting in tyre wear Slight tendency to oversteer
Semi-trailing arms – variable length drive shafts	The final drive assembly is mounted to the body and two UJs are used on each shaft	The two arms are independent of each other Only slight track changes	Large camber changes High cost because of the drive shafts and joints

7.9.4 Rear axle suspensions

Table 7.6 compares the common rear axle suspension systems.

7.9.5 Anti-roll bar

The main purpose of an anti-roll bar is to reduce body roll on corners. The anti-roll bar can be thought of as a torsion bar. The centre is pivoted on the body

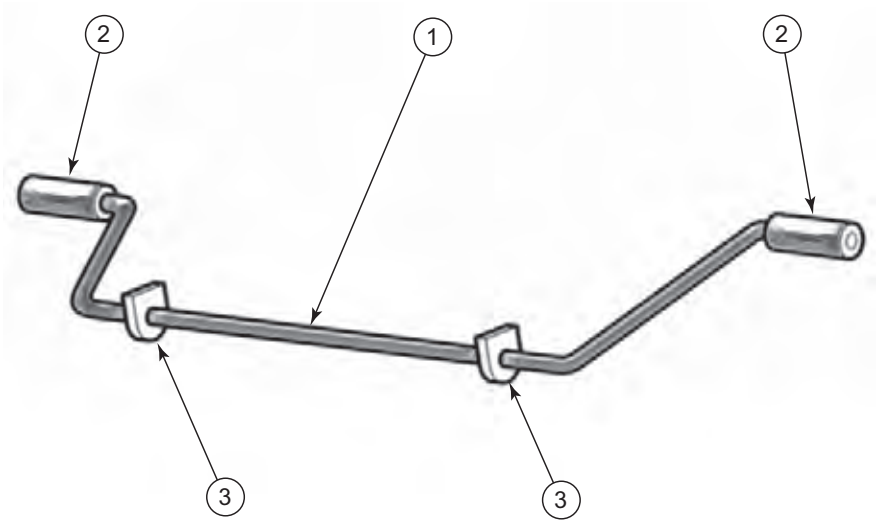


Figure 7.32 Anti-roll bar: 1 – torsion bar; 2 – pivots on suspension lower arms; 3 – to vehicle body

and each end bends to make connection with the suspension/wheel assembly. When the suspension is compressed on both sides, the anti-roll bar has no effect because it pivots on its mountings (Figure 7.32).

As the suspension is compressed on just one side, a twisting force is exerted on the anti-roll bar. The anti-roll bar is now under torsional load. Part of this load is transmitted to the opposite wheel, pulling it upwards. This reduces the amount of body roll on corners. The disadvantages are that some of the 'independence' is lost and the overall ride is harsher. Anti-roll bars can be f tted to both front and rear axles.

7.9.6 Springs

The requirements of the springs can be summarised as follows:

- absorb road shocks from uneven surfaces;
- control ground clearance and ride height;
- ensure good tyre adhesion;
- support the weight of the vehicle;
- transmit gravity forces to the wheels.

There are a number of different types of spring in use on modern light vehicles. Table 7.7 lists these together with their main features.

Key fact

Strictly speaking, a damper damps out spring oscillations, but as it also absorbs shock it is also called a shock absorber

7.9.7 Dampers

The functions of a damper can be summarised as follows (Figure 7.33):

- ensure directional stability;
- ensure good contact between the tyres and the road;

Table 7.7 Spring features

Name	Comments	Characteristics
Coil springs	The most common spring currently in use on light vehicles. The coil spring is a torsion bar wound into a spiral	Can be progressive if the diameter of the spring is tapered conically Cannot transmit lateral or longitudinal forces, hence the need for links or arms Little internal damping Little or no maintenance High travel
Leaf springs	These springs can be single or multiple leaf. They are most often mounted longitudinally Nowadays they are only used on commercial vehicles	Can transmit longitudinal and lateral forces Short travel High internal damping High load capacity Maintenance may be required Low height but high weight
Torsion bar springs	A torsion bar is a spring where twisting loads are applied to a steel bar They can be round or square section, solid or hollow Their surface must be finished accurately to eliminate pressure points, which may cause cracking ar fatigue failure. They can be fitted longitudinally or laterally	Maintenance free but can be adjusted Transmit longitudinal and lateral forces Limited self-damping Linear rate Low weight May have limited fatigue life
Rubber springs	Nowadays rubber springs are only used as a supplement to other forms of springs. They ar however, popular on trailers and caravans	Progressive rate Transmit longitudinal and lateral forces Short travel Low weight and low cost Their springing and damping properties can change with temperature
Air springs	Air springs can be thought of as being like a balloon or football on which the car is supported. The system involves compressors and air tanks. They are not normally used on light vehicles	Expensive Good-quality ride Electronic control can be used Progressive spring rate High production cost
Hydro-pneumatic springs	A hydro-pneumatic spring is a gas spring wit hydraulic force transmission. Nitrogen is usual used as the gas. The damper can be built i as part of the hydraulic system. The springs can be hydraulically connected together to reduce pitch or roll. Ride height control can be achieved by pumping oil into or out of th working chamber	Progressive rate Ride height control Damping built-in Pressurised oil supply is required Expensive and complicated

- prevent build-up of vertical movements;
- reduce oscillations;
- reduce wear on tyres and chassis components.

There are a number of different types of damper. These are listed in Table 7.8.

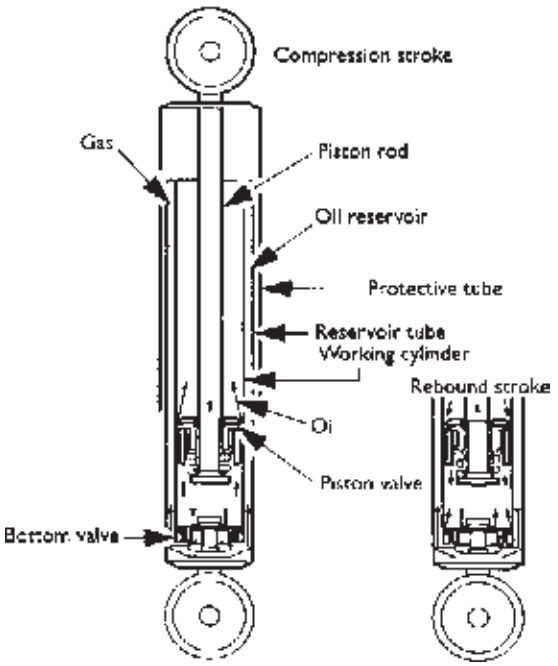


Figure 7.33 Twin-tube gas damper

Table 7.8 Types of damper

Friction damper	Not used on cars today, but you will find this system used as part of caravan or trailer stabilisers
Lever-type damper	Used on earlier vehicles, the lever operates a piston which forces oil into a chamber
Twin-tube telescopic damper	This is a commonly used type of damper; it consists of two tubes. An outer tube forms a reservoir space and contains the oil displaced from an inner tube. Oil is forced through a valve by the action of a piston as the damper moves up or down. The reservoir space is essential to make up for the changes in volume as the piston rod moves in and out
Single-tube telescopic damper	This is often referred to as a gas damper. However, the damping action is still achieved by forcing oil through a restriction. The gas space behind a separator piston is to compensate for the changes in cylinder volume caused as the piston rod moves. It is at a pressure of approximately 25 bar
Twin-tube gas damper (Figure 7.33)	The twin-tube gas damper is an improvement on the well-used twin-tube system. The gas cushion is used in this case to prevent oil foaming. The gas pressure on the oil prevents foaming, which in turn ensures constant operation under all operating conditions. Gas pressure is lower than for a single-tube damper at approximately 5 bar
Variable rate damper	This is a special variation of the twin-tube gas damper. The damping characteristics vary depending on the load on the vehicle. Bypass grooves are machined in the upper half of the working chamber. With light loads, the damper works in this area with a soft damping effect. When the load is increased, the piston moves lower down the working chamber away from the grooves resulting in full damping effect
Electronically controlled dampers	These are dampers where the damping rate can be controlled by solenoid valves inside the units. With suitable electronic control, the characteristics can be changed within milliseconds to react to driving and/or load conditions

7.10 Diagnostics – Suspension

7.10.1 Systematic testing

If the reported fault is poor handling, proceed as follows:

1 Road test to conf rm the fault.
2 With the vehicle on a lift, inspect obvious items like tyres and dampers.
3 Consider if the problem is suspension related or in the steering, for example. You may have decided this from road testing.
4 Inspect all the components of the system you suspect; for example, dampers for correct operation and suspension bushes for condition and security. Let's assume the fault was one front damper not operating to the required standard.
5 Renew both of the dampers at the front to ensure balanced performance.
6 Road test again and check for correct operation of the suspension and other systems.

7.10.2 Test equipment

7.10.2.1 Damper tester

The operating principle of a damper tester is shown in Figure 7.34, which indicates that the damper is not operating correctly in this case. This is a device that will draw a graph to show the response of the dampers. It may be useful for providing paper evidence of the operating condition but a physical examination is normally adequate.

Safety f rst

Note: You should always refer to the manufacturer's instructions appropriate to the equipment you are using.

7.10.3 Test results

Some of the information you may have to get from other sources such as data books or a workshop manual is listed in Table 7.9.

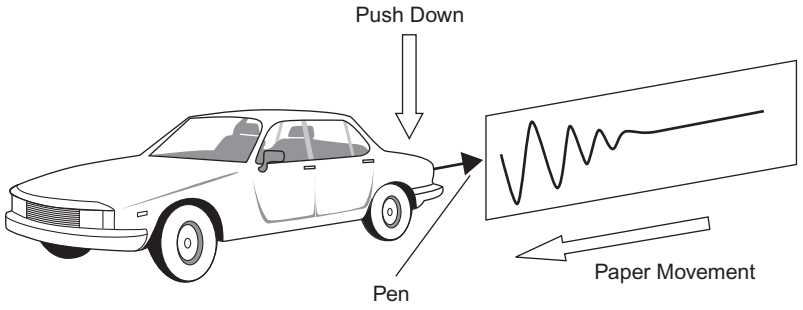


Figure 7.34 Representation of a damper (shock absorber) test – the symptoms suggest a faulty damper

Table 7.9 Tests and information required

Test carried out	Information required
Damper operation	The vehicle body should move down as you press on it, bounce back just past the start point and then return to the rest position
Suspension bush condition	Simple levering, if appropriate, should not show excessive movement, cracks or separation of rubber bushes
Trim height	This is available from data books as a measurement from say the wheel centre to a point on the car wing above

7.10.4 Suspension fault diagnosis table 1

Symptom	Possible faults	Suggested action
Excessive pitch or roll when driving	Dampers worn	Replace in pairs
Car sits lopsided	Broken spring Leak if hydraulic suspension	Replace in pairs Rectify by replacing unit ottifng new pipes
Knocking noises	Excessive free play in a suspension joint	Renew
Excessive tyre wear	Steering/suspension geometry incorrect (may be due to accident damage)	Check and adjust or replace any 'bent' or out of true components

7.10.5 Suspension fault diagnosis table 2

Symptom	Possible cause
Excessive pitching	Defective dampers Broken or weak spring Worn or damaged anti-roll bar mountings
Wandering or instability	Broken or weak spring Worn suspension joints Defective dampers
Wheel wobble	Worn suspension joints
Pulling to one side	Worn suspension joints Accident damage to suspension alignment
Excessive tyre wear	Worn suspension joints Accident damage to suspension alignment Incorrect trim height (particularly hydrolastic systems)

7.11 Active Suspension

7.11.1 Active suspension operation

A traditional or a conventional suspension system, consisting of springs and dampers, is passive. In other words, once it has been installed in the car, its characteristics do not change (Figure 7.35).

The main advantage of a conventional suspension system is its predictability. Over time, the driver will become familiar with a car's suspension and understand its capabilities and limitations. The disadvantage is that the system has no way of compensating for situations beyond its original design (Figure 7.36).

Key fact

An active suspension system has the ability to adjust itself continuously

An active suspension system (also known as computerized ride control) has the ability to adjust itself continuously. It monitors and adjusts its characteristics to suit the current road conditions. As with all electronic control systems, sensors supply information to an ECU which in turn outputs to actuators. By changing its characteristics in response to changing road conditions, active suspension offers improved handling, comfort, responsiveness and safety (Figure 7.37).

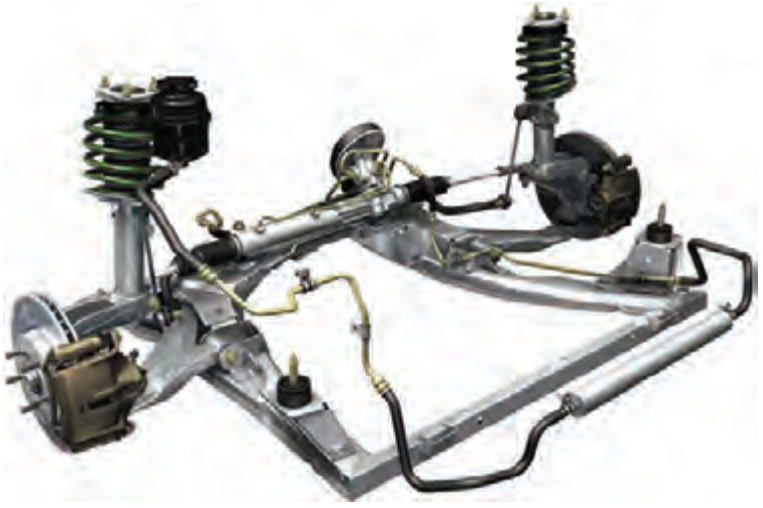


Figure 7.35 Jaguar suspension system(Source: Jaguar Media)



Figure 7.36 Suspension system(Source: Ford Media)



Figure 7.37 Active suspension also allows adjustments; in this case, between sport and comfort settings(Source: Volkswagen Media)



Figure 7.38 Potholes

Active suspension systems consist of the following components:

- electronic control unit;
- adjustable dampers and springs;
- sensors at each wheel and throughout the car;
- levelling compressor (some systems).

Components vary between manufacturers, but the principles are the same.

Active suspension works by constantly sensing changes in the road surface and feeding that information to the ECU, which in turn controls the suspension springs and dampers. These components then act upon the system to modify the overall suspension characteristics by adjusting damper stiffness, ride height (in some cases) and spring rate.

Assume that a car with conventional suspension is cruising down the road and then, after turning left, hits a series of potholes on the right-hand side, each one larger than the next (Figure 7.38). This would present a serious challenge to a conventional suspension system because the increasing size of the holes could set up an oscillation loop and bottom out the system. An active system would react very differently.

Sensors send information to the ECU about yaw and lateral acceleration. Other sensors measure excessive vertical travel, particularly in the right-front region of the car, and a steering angle sensor provides information on steering position.

The ECU analyses this information in approximately 10 ms. It then sends a signal to the right-front spring to stiffen up. A similar signal is sent to the right-rear spring, but this will not be stiffened as much. The rigidity of the suspension dampers on the right-hand side of the vehicle is therefore increased. Because of these actions, the vehicle will drive through the corner, with little impact on driveability and comfort.

One of the latest types of sensor is produced by Bosch. The sensor simultaneously monitors three of a vehicle's movement axes – two acceleration



Figure 7.39 Integrated sensor(Source: Bosch Media)



Figure 7.40 Suspension strut and actuator connection(Source: Delphi Media)

or inclination axes (*ax*, *ay*) and one axis of rotation (Ω*z*). Previously, at least two separate sensors were required for this. The integration of the sensors for lateral acceleration and yaw rate reduces space requirements in the vehicle and the assembly work for the complete system (Figure 7.39).

There are a number of ways of controlling the suspension. However, in most cases it is done by controlling the oil restriction in the damper. On some systems, ride height is controlled by opening a valve and supplying pressurised f uid from an engine-driven compressor.

Other systems use special f uid in the dampers that reacts to a magnetic f eld, which is applied from a simple electromagnetic coil. The case study of a Delphi system in the next section looks at this method in detail (Figure 7.40).

The improvements in ride comfort are considerable, which is why active suspension technology is becoming more popular. In simple terms, sensors provide the input to a control system that in turn actuates the suspension dampers in a way that improves stability and comfort.

7.11.2 Delphi MagneRide case study

MagneRide was the industry's f rst semi-active suspension technology that employs no electro-mechanical valves and small moving parts. The MagneRide magneto-rheological (MR) f uid-based system consists of MR f uid-based single-tube struts, shock absorbers (dampers), a sensor set and an on-board controller (Figure 7.41).

MR f uid is a suspension of magnetically soft particles such as iron microspheres in a synthetic hydrocarbon base f uid. When MR f uid is in the 'off' state, it is not magnetised, and the particles exhibit a random pattern. But in the 'on' or magnetised state, the applied magnetic f eld aligns the metal particles into f brous structures, changing the f uid rheology to a near plastic state (Figure 7.42).

Def nition

Rheology: The study of friction between liquids.



Figure 7.41 MagneRide suspension components (Source: Delphi Media)

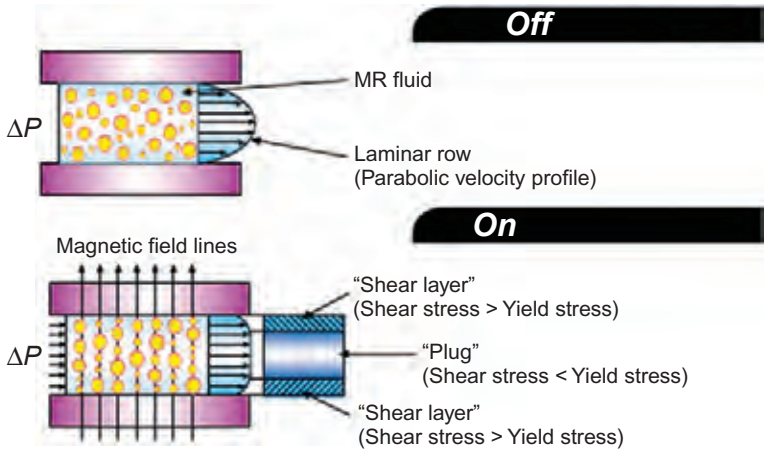


Figure 7.42 Fluid in the on and off states (Source: Delphi Media)

By controlling the current to an electromagnetic coil inside the piston of the damper, the MR f uid's shear strength is changed, varying the resistance to f uid f ow. Fine-tuning of the magnetic current allows for any state between the low forces of 'off' to the high forces of 'on' to be achieved in the damper. The result is continuously variable real-time damping (Figure 7.43).

The layout in Figure 7.44 shows the inputs and outputs of the MagneRide system. Note the connections with the ESP system and how the information is shared over the controller area network (CAN).

The MagneRide system, produced by Delphi, uses a special f uid in the dampers. The properties of this f uid are changed by a magnetic f eld. This allows for very close control of the damping characteristics and a signif cant improvement in ride comfort and quality.

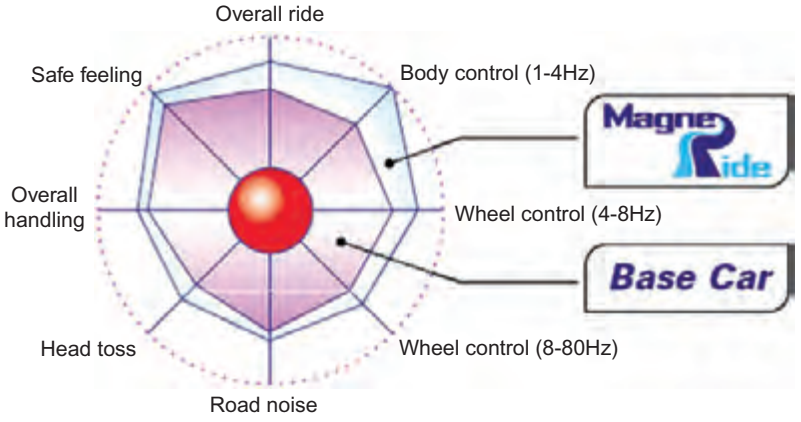


Figure 7.43 Representation of improvements when suspension is controlled (Source: Delphi Media)

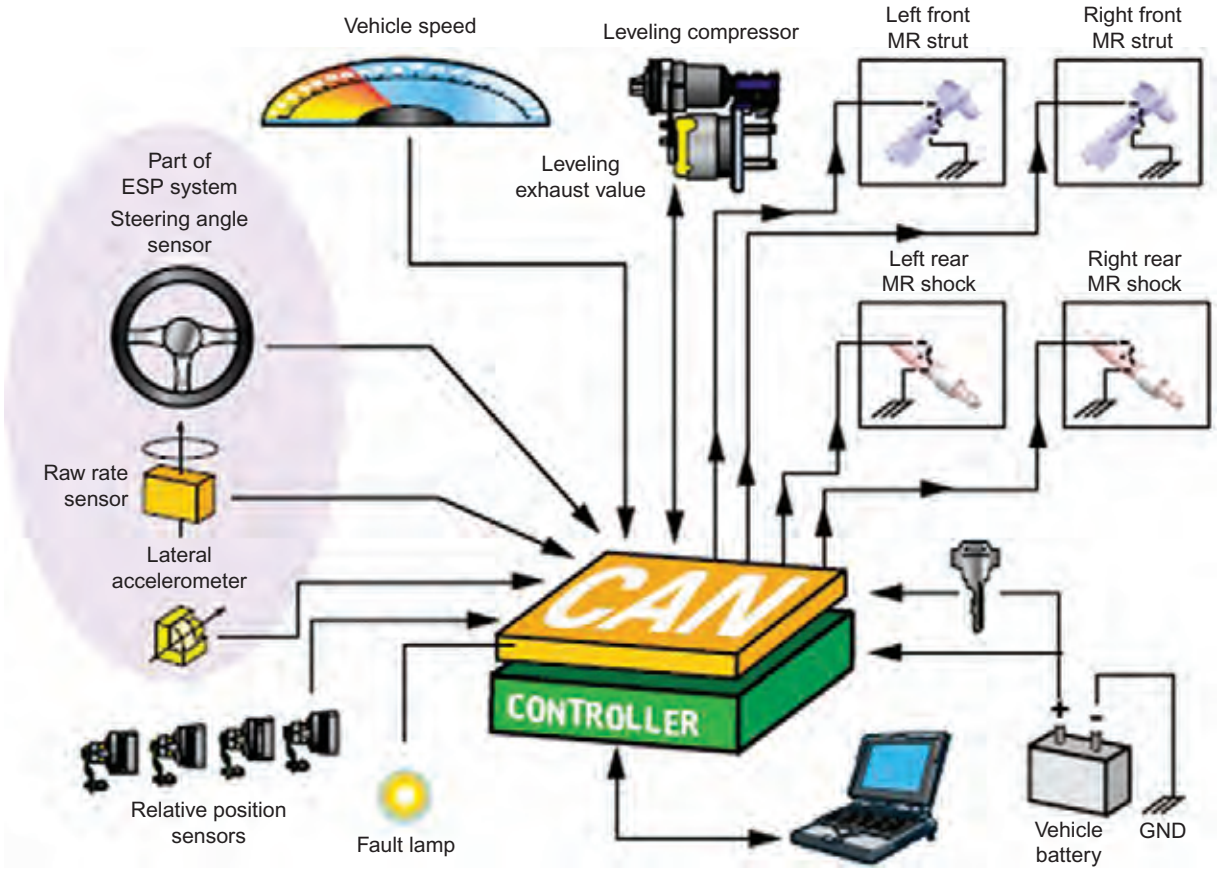


Figure 7.44 Control system(Source: Delphi Media)

7.12 Diagnostics – active suspension

7.12.1 Systematic testing

Even for an active system it may be useful to treat it like a conventional system at f rst. If the reported fault is poor handling and/or an MIL and code indicates a suspension problem, proceed as follows:

1 Conf rm the fault and scan for codes.

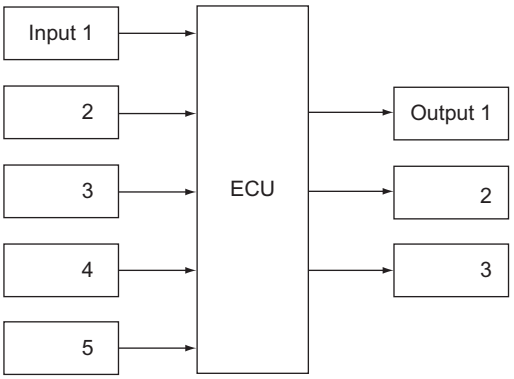


Figure 7.45 System block diagram

2 With the vehicle on a lift, inspect obvious items like tyres and dampers for leaks.
3 Inspect all the components of the system you suspect and look for leaks.
4 Check mountings for damage and sensor wiring.
5 Check sensors and actuators (see section 7.12.2 and chapter 4).

7.12.2 Back to the black box

Key fact

Most vehicle systems involve an ECU.

Active suspension systems now revolve around an ECU, and the ECU can be considered to be a 'black box'; in other words, we know what it should do but the exact details of how it does it are less important.

Treating the ECU as a 'black box' allows us to ignore its complexity. The theory is that if all the sensors and associated wiring to the 'black box' are OK, all the output actuators and their wiring are OK and the supply/earth (ground) connections are OK, then the fault must be in the 'black box'. Most ECUs are very reliable, however, and it is far more likely that the fault will be found in the inputs or outputs (Figure 7.45).

Key fact

If the readings of all similar items connected to an ECU are the same, then it is reasonable to assume the figure is almost certainly correct.

Normal fault-finding or testing techniques can be applied to the sensors and actuators. For example, if the system uses four movement sensors, then an easy test is to measure their output. Even if the correct value is not known, it would be very unlikely for all four to be wrong at the same time so a comparison can be made. If the same reading is obtained on the end of the sensor wires at the ECU, then almost all of the 'inputs' have been tested with just a few readings. The same technique will often work with 'outputs'.

Don't forget that no matter how complex the electronics in an ECU, they will not work without a good power supply and an earth.

CHAPTER

Electrical systems

8.1 Electronic components and circuits

8.1.1 Introduction

This section describing the principles and applications of various electronic components and circuits is not intended to explain their detailed operation. Overall, an understanding of basic electronic principles will help to show how electronic systems operate. These can range from a simple interior light delay unit to the most complicated engine management system. Testing individual electronic components is a useful diagnostic procedure.

8.1.2 Components

The symbols for the electronic components discussed in this section are shown in Figure 8.1.

Resistors are probably the most widely used component in electronic circuits. Two factors must be considered when choosing a suitable resistor: the ohms value and the power rating. Resistors are used to limit current f ow and provide f xed voltage drops. Most resistors used in electronic circuits are made from small carbon rods; the size of the rod determines the resistance. Carbon resistors have a negative temperature coeff cient (NTC) and this must be considered for some applications. Thin-f lm resistors have more stable temperature properties and are constructed by depositing a layer of carbon onto an insulated former such as glass. The resistance value can be manufactured very accurately by spiral grooves cut into the carbon f lm. For higher power applications, resistors are usually wire wound. Variable forms of most resistors are available. The resistance of a circuit is its opposition to current f ow.

Key fact

Resistors are used to limit current f ow and provide f xed voltage drops.

A capacitor is a device for storing an electric charge. In its simple form, it consists of two plates separated by an insulating material. One plate can have excess electrons compared to the other. On vehicles, its main uses are for reducing arcing across contacts and for radio interference suppression circuits as well as in electronic control units (ECUs). Capacitors are described as two plates separated by a dielectric. The area of the plates, the distance between them and the nature of the dielectric determine the value of capacitance. Metal foil sheets insulated by a type of paper are often used to construct capacitors. The sheets are rolled up together inside a tin can. To achieve higher values of capacitance it is necessary to reduce the distance between the plates in order to keep the overall size of the device manageable. This is achieved

Key fact

A capacitor is a device for storing an electric charge.

Advanced Automotive Fault Diagnosis.
© 2012 Tom Denton. Published by Routledge. All rights reserved.

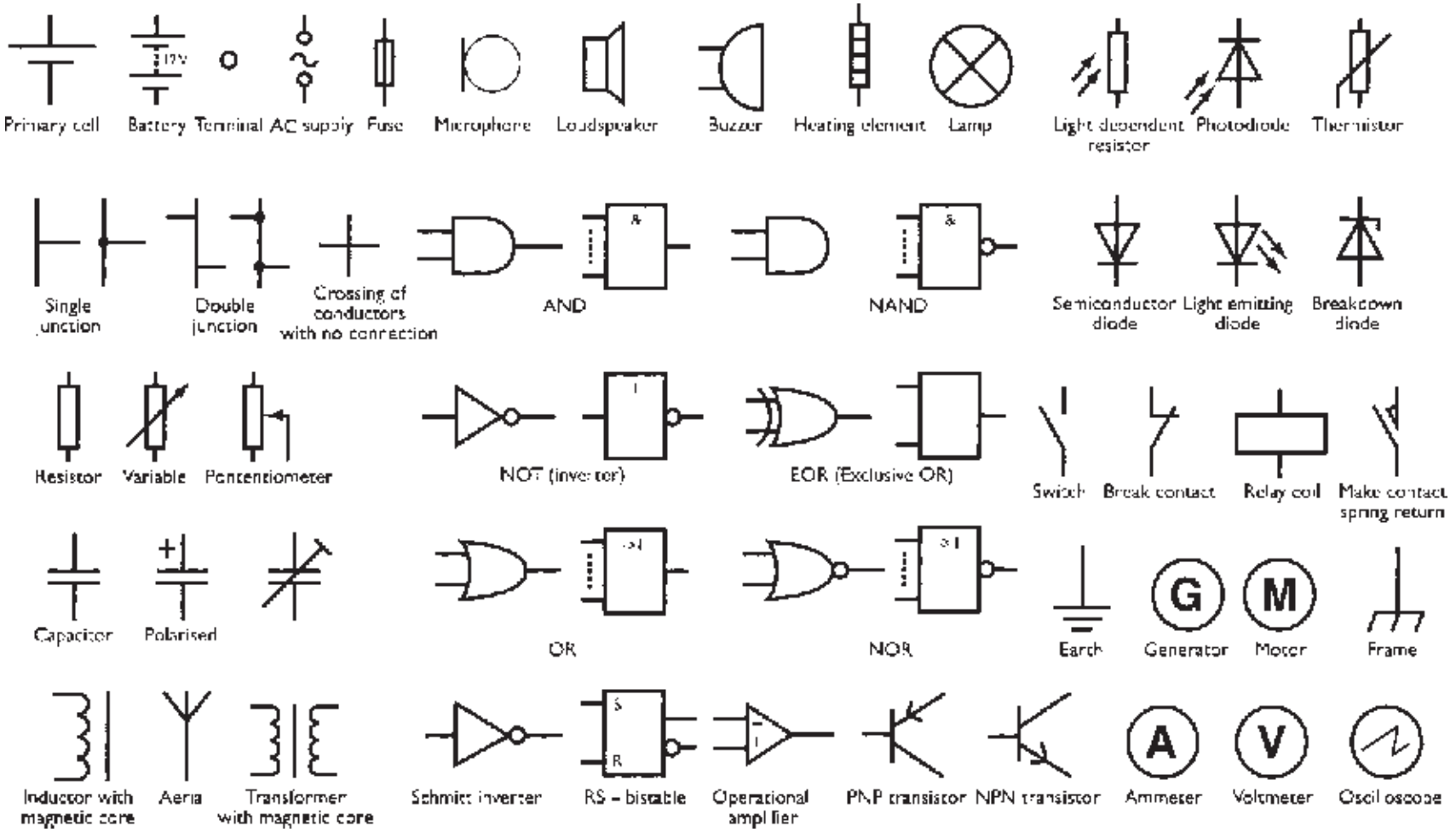


Figure 8.1 Circuit symbols

by immersing one plate in an electrolyte to deposit a layer of oxide typically 10^{-4} mm thick, thus ensuring a higher capacitance value. The problem, however, is that this now makes the device polarity conscious and only able to withstand low voltages.

Diodes are often described as one-way valves, and for most applications, this is an acceptable description. A diode is a PN junction allowing electron flow from the N-type material to the P-type material. The materials are usually constructed from doped silicon. Diodes are not perfect devices and a voltage of approximately 0.6 V is required to switch the diode on in its forward biased direction.

Key fact

Diodes are often described as one-way valves.

Zener diodes are very similar in operation with the exception that they are designed to breakdown and conduct in the reverse direction at a predetermined voltage. They can be thought of as a type of pressure relief valve.

Transistors are the devices that have allowed the development of today's complex and small electronic systems. The transistor is used as either a solid state switch or as an amplifier. They are constructed from the same P- and N-type semiconductor materials as the diodes and can be made in either NPN or PNP format. The three terminals are known as the base, collector and emitter. When the base is supplied with the correct bias, the circuit between the collector and emitter will conduct. The base current can be in the order of 50–200 times less than the emitter current. The ratio of the current flowing through the base compared to the current through the emitter is an indication of the amplification factor of the device.

Key fact

The transistor is used as either a solid state switch or as an amplifier

A Darlington pair is a simple combination of two transistors which will give a high current gain, typically several thousand. The transistors are usually mounted on a heat sink and overall the device will have three terminals marked as a single transistor – base, collector and emitter. The input impedance of this type of circuit is in the order of 1 MΩ; hence, it will not load any previous part of a circuit connected to its input. The Darlington pair configuration is used for many switching applications. A common use of a Darlington pair is for the switching of coil primary current in the ignition circuit.

Another type of transistor is the field effect transistor (FET). This device has higher input resistance than the bipolar type described above. They are constructed in their basic form as n-channel or p-channel devices. The three terminals are known as the gate, source and drain. The voltage on the gate terminal controls the conductance of the circuit between the drain and the source.

Inductors are most often used as part of an oscillator or amplifier circuit. The basic construction of an inductor is a coil of wire wound on a former. It is the magnetic effect of the changes in current flow which gives this device the properties of inductance. Inductance is a difficult property to control particularly as the inductance value increases. This is due to magnetic coupling with other devices. Iron cores are used to increase the inductance value.

This also allows for adjustable devices by moving the position of the core. Inductors, particularly of higher values, are often known as chokes and may be used in DC circuits to smooth the voltage.

Key fact

Integrated circuits or ICs are constructed on a single slice of silicon often known as a substrate.

8.1.3 Integrated circuits

Integrated circuits (ICs) are constructed on a single slice of silicon often known as a substrate. Combinations of some of the components mentioned previously can be used to carry out various tasks such as switching, amplifying and logic

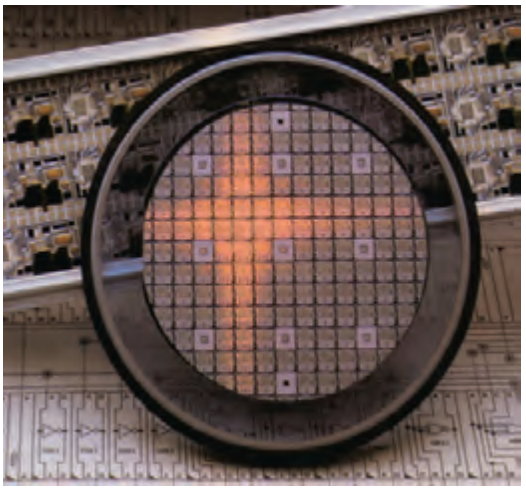


Figure 8.2 Silicon wafer used in the construction of integrated circuits

functions. The components required for these circuits can be made directly onto the slice of silicon. The great advantage of this is not just the size of the ICs but the speed at which they can be made to work due to the short distances between components. Switching speed in excess of 1 MHz is typical.

The range and type of integrated circuits now available is so extensive that a chip is available for almost any application. The integration level of chips is now exceeding VLSI (very large scale integration). This means that there can be more than 100 000 active elements on one chip. Development in this area is moving so fast that often the science of electronics is now concerned mostly with choosing the correct combination of chips, and discrete components are only used as f nal switching or power output stages. Figure 8.2 shows a highly magnif ed view of a typical IC.

8.1.4 Digital circuits

With some practical problems, it is possible to express the outcome as a simple yes/no or true/false answer. Let's take a simple example: if the answer to the f rst or the second question is 'yes', then switch on the brake warning light; if both answers are 'no' then switch it off.

1 Is the handbrake on?
2 Is the level in the brake f uid reservoir low?

In this case, we need the output of an electrical circuit to be 'on' when either one or both of the inputs to the circuit are 'on'. The inputs will be via simple switches on the handbrake and in the brake reservoir. The digital device required to carry out the above task is an OR gate. An OR gate for use on this system would have two inputs (a and b) and one output (c). Only when 'a' OR 'b' is supplied, will 'c' produce a voltage.

Once a problem can be described in logic states then a suitable digital or logic circuit can also determine the answer to the problem. Simple circuits can also be constructed to hold the logic state of their last input; these are in effect simple forms of 'memory'. By combining vast quantities of these basic digital building blocks, circuits can be constructed to carry out the most complex tasks in a fraction of a second. Because of IC technology, it is now possible to

create hundreds of thousands if not millions of these basic circuits on one chip. This has given rise to the modern electronic control systems used for vehicle applications as well as all the countless other uses for a computer.

In electronic circuits, true/false values are assigned voltage values. In one system, known as TTL (transistor–transistor–logic), true or logic '1' is represented by a voltage of 3.5 V and false or logic '0' by 0 V.

Key fact

In electronic circuits, true/false values are assigned voltage values.

8.1.5 Electronic component testing

Individual electronic components can be tested in a number of ways but a digital multimeter is normally the favourite option. Table 8.1 suggests some methods of testing components removed from the circuit (Figures 8.3 and 8.4).

Table 8.1 Electronic component test methods

Component	Test method
Resistor	Measure the resistance value with an ohmmeter and compare this to the value written or colour coded on the component
Capacitor	A capacitor can be difficult to test without specialist equipment but try this. Charge the capacitor up to 12 V and connect it to a digital voltmeter. As most digital meters have an internal resistance of approximately 10 MΩ, calculate the expected discharge time ($T = 5CR$) and see if the device complies. A capacitor from a contact breaker ignition system should take approximately five seconds to discharge in this way
Inductor	An inductor is a coil of wire, so a resistance check is the best method to test for continuity
Diode	Many multimeters have a diode test function. If so, the device should read open circuit in one direction and approximately 0.4–0.6 V in the other direction. This is its switch on voltage. If no meter is available with this function, then wire the diode to a battery via a small bulb; it should light with the diode one way and not the other
LED	LEDs can be tested by connecting them to a 1.5 V battery. Note the polarity though; the longest leg or the flat side of the case is negative
Transistor (bipolar)	Some multimeters even have transistor testing connections but, if not available, the transistor can be connected into a simple circuit as Figure 8.4 and voltage tests carried out as shown. This also illustrates a method of testing electronic circuits in general. It is fair to point out that without specific data it is difficult for the non-specialist to test unfamiliar circuit boards. It is always worth checking for obvious breaks and dry joints though
Digital components	A logic probe can be used. This is a device with a very high internal resistance, so it does not affect the circuit under test. Two different coloured lights are used; one glows for a 'logic 1' and the other for 'logic 0'. Specific data is required in most cases but basic tests can be carried out



Figure 8.3 Electronic components

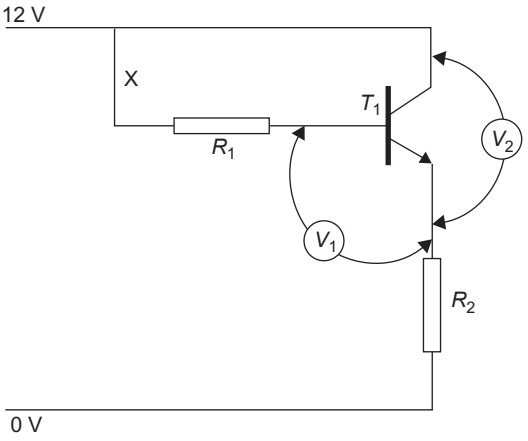


Figure 8.4 Transistor testing: Use resistors $R_1 = R_2$ of approximately 1 kΩ, when connected as shown, V_1 should read 0.6–0.7 V and V_2 approximately 1 V. Disconnect wire X, V_1 should now read 0 V and V_2 12 V

8.2 Multiplexing

8.2.1 Overview

Def nition

CAN: Controller area network.

The number of vehicle components which are networked has considerably increased the requirements for the vehicle control systems to communicate with one another. The CAN (controller area network) developed by Bosch is today's communication standard in passenger cars. However, there are a number of other systems.

Multiplexing is a process of combining several messages for transmission over the same signal path. The signal path is called the data bus. The data bus is basically just a couple of wires connecting the control units together. A data bus consists of a communication or signal wire and a ground return, serving all multiplex system nodes. The term 'node' is given to any sub-assembly of a multiplex system (such as a control unit) that communicates on the data bus.

On some vehicles, early multiplex systems used three control units (Figure 8.5). These were the door control unit, the driver's side control

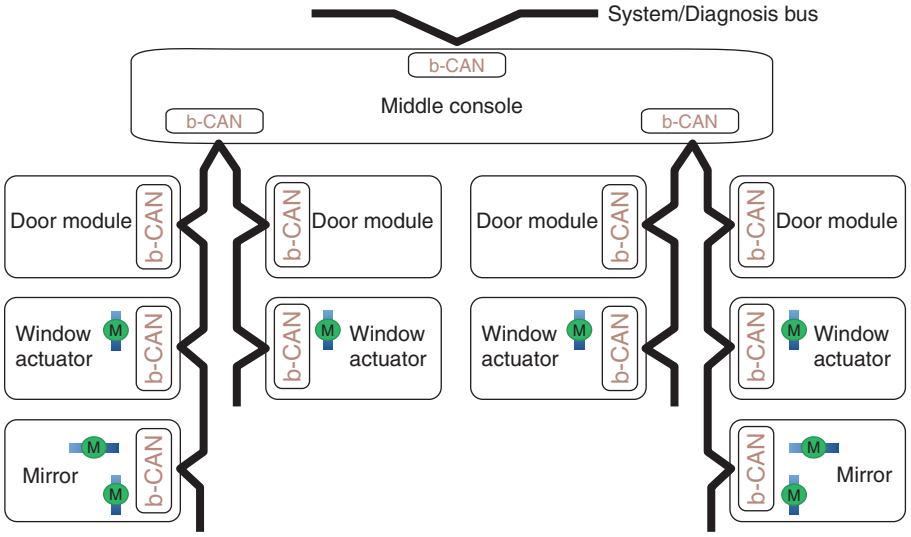


Figure 8.5 Sub-system for doors on an earlier system

unit and the passenger's side control unit. These three units replaced the following:

- integrated unit;
- interlock control unit;
- door lock control unit;
- illumination light control;
- power window control unit;
- security alarm control unit.

When a switch is operated, a coded digital signal is generated and communicated, according to its priority, via the data bus. All control units receive the signal but only the control unit for which the signal is intended will activate the desired response.

Only one signal can be sent on the BUS at any one time. Therefore, each signal has an identif er that is unique throughout the network. The identif er def nes not only the content but also the priority of the message. Some systems make changes or adjustments to their operation much faster than other systems. Therefore, when two signals are sent at the same time, it is the system which requires the message most urgently whose signal takes priority (Figure 8.6).

A multiplex control system has the advantage of self-diagnosis. This allows quick and easy troubleshooting and verif cation using diagnostic trouble codes (DTCs).

Many vehicles contain over a kilometre of wiring to supply all their electrical components. Luxury models may contain considerably more because of elaborate drivers' aids. The use of multiplexing means that considerably less wiring is used in a vehicle along with fewer multi-plugs and connectors, etc. An additional advantage of multiplexing is that existing systems can be upgraded or added to without modif cation to the original system.

8.2.2 Controller area network

CAN is a serial bus system especially suited for networking 'intelligent' devices as well as sensors and actuators within a system or sub-system. It operates in

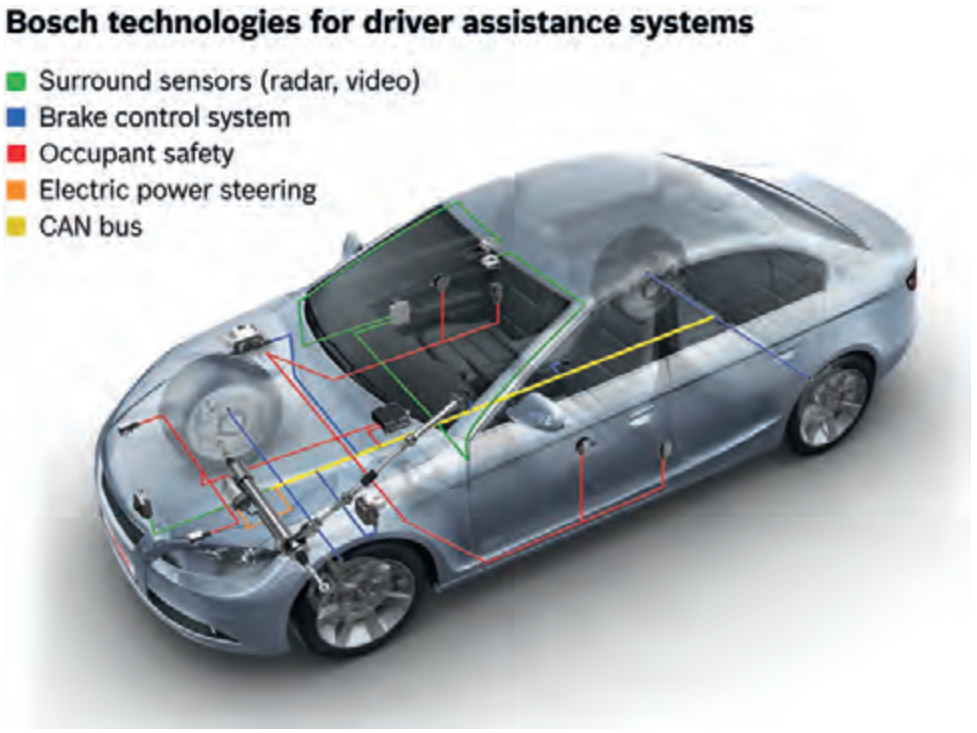


Figure 8.6 A data bus connects all networked components

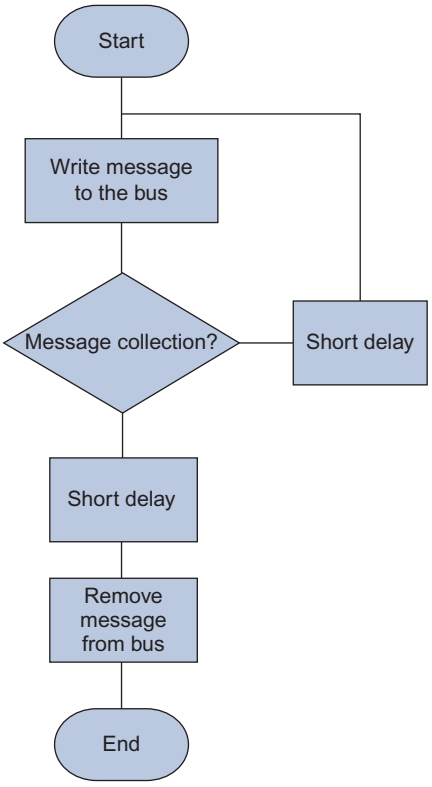


Figure 8.7 Much simplifed CAN message protocol flowchart

a broadly similar way to a wired computer network. CAN stands for controller area network and means that control units are able to interchange data. CAN is a high-integrity serial data communications bus for real-time applications. It operates at data rates of up to 1 Mbit/s. It also has excellent error detection and conf nement capabilities. It was originally developed by Bosch for use in cars but is now used in many other industrial automation and control applications.

CAN is a serial bus system with multi-master capabilities. This means that all CAN nodes are able to transmit data and several CAN nodes can request use of the bus simultaneously. In CAN networks, there is no addressing of subscribers or stations, like on a computer network, but instead, prioritized messages are transmitted. A transmitter sends a message to all CAN nodes (broadcasting). Each node decides on the basis of the identif er received whether it should process the message or not. The identif er also determines the priority that the message enjoys in competition for bus access (Figure 8.7).

Fast controller area network (F-CAN) and basic (or body) controller area network (B-CAN) share information between multiple ECUs. B-CAN communication is transmitted at a slower speed for convenience related items such as electric windows. F-CAN information moves at a faster speed for real-time functions such as fuel and emissions systems. To allow both systems to share information, a control module translates information between B-CAN and F-CAN (Figure 8.8).

The ECUs on the B-CAN and F-CAN transmit and receive information in the form of structured messages that may be received by several different ECUs on the network at one time. These messages are transmitted and received across a communication circuit that consists of a single wire that is shared by all the ECUs. However, as messages on the F-CAN network are typically of higher importance, a second wire is used for communication circuit integrity monitoring. This CAN-high and CAN-low circuit forms the CAN bus (Figure 8.9).

Key fact

CAN is a serial bus system with multi-master capabilities.

Key fact

Fast controller area network (F-CAN) and basic (or body) controller area network (B-CAN) share information between multiple electronic control units (ECUs).

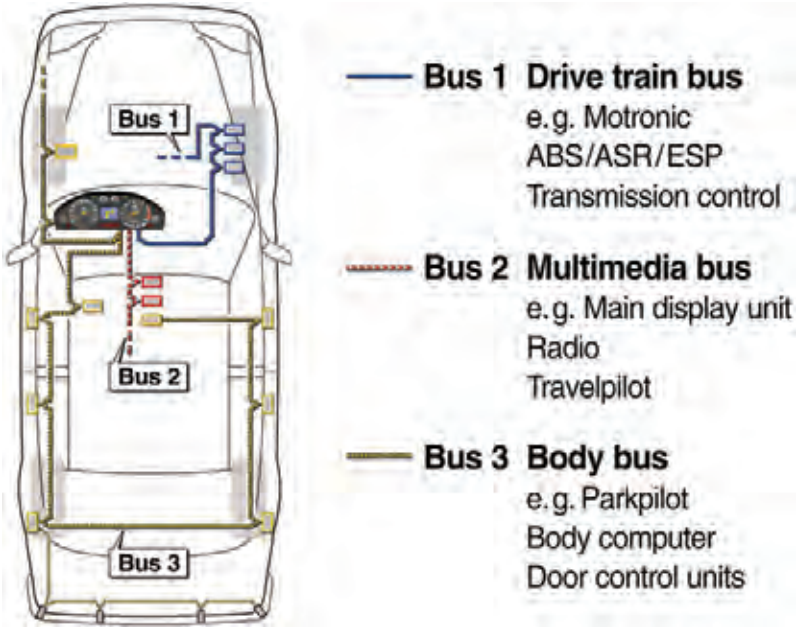


Figure 8.8 Three different speed buses in use (Source: Bosch Media)

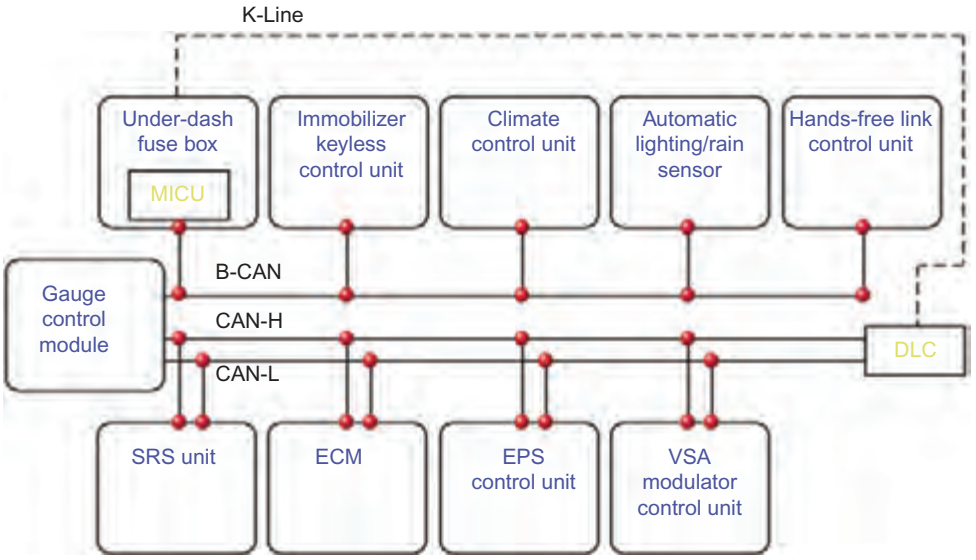


Figure 8.9 F-CAN uses CAN-H (high) and CAN-L (low) wires

A multiplex control unit is usually combined with the under-dash fuse/relay box. It controls many of the vehicle systems related to body electrics and the B-CAN. It also carries out much of the remote switching of various hardwired and CAN-controlled systems.

One of the outstanding features of the CAN protocol is its high transmission reliability. The CAN controller registers a station's error and evaluates it statistically in order to take appropriate measures. These may extend to disconnecting the CAN node producing the errors (Figure 8.10).

Each CAN message can transmit from 0 to 8 bytes of user information. Longer messages can be sent by using segmentation, which means slicing a longer message into smaller parts. The maximum transmission rate is specif ed as

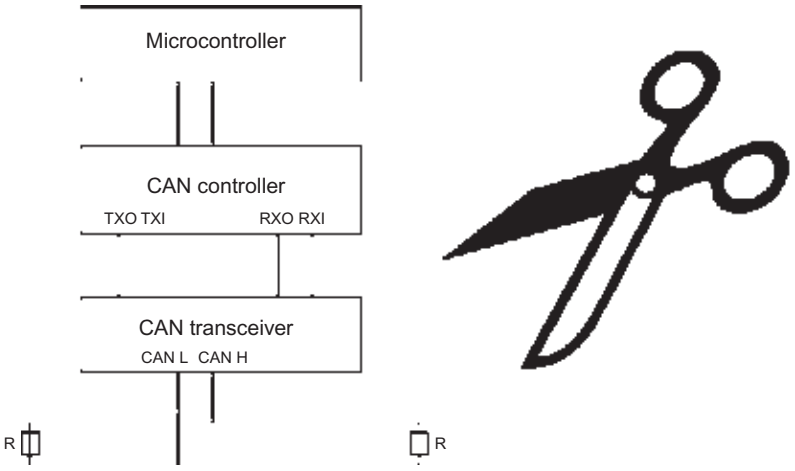


Figure 8.10 CAN nodes can be disconnected by the control program

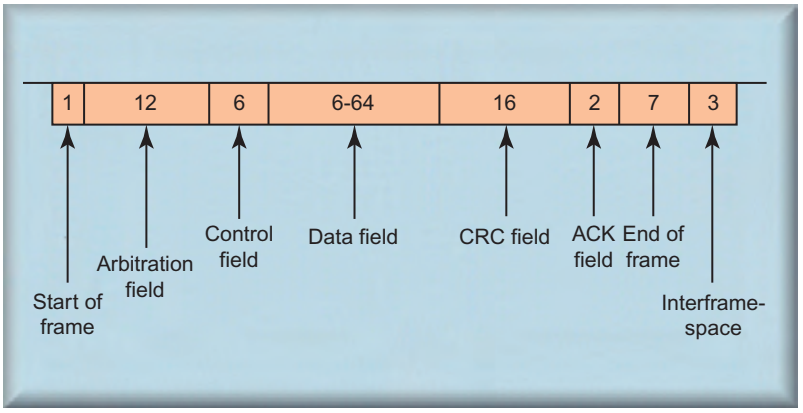


Figure 8.11 Message format (the three spaces are not part of the message)

1 Mbit/s. This value applies to networks up to 40 m which is more than enough for normal cars and trucks.

CAN is a serial bus system designed for networking ECUs as well as sensors and actuators.

8.2.3 CAN data signal

Key fact

The CAN message signal consists of a sequence of binary digits or bits.

The CAN message signal consists of a sequence of binary digits or bits. A high voltage present indicates the value 1, a low or no voltage indicates 0. The actual message can vary between 44 and 108 bits in length. This is made up of a start bit, name, control bits, the data itself, a cyclic redundancy check (CRC) for error detection, a conf rmation signal and f nally a number of stop bits (Figure 8.11).

A binary format message can be something like 10001010100010101111100001 11010111101010101010001111101011110011001100000111111010101000011 11111111000000001

3-452 Section of an actual electrical signal

The message identif er or name portion of the signal (part of the arbitration f eld) identif es the message destination and also its priority. As the transmitter

puts a message on the data bus it also reads the name back from the bus. If the name is not the same as the one it sent, then another transmitter must be in operation, which has a higher priority. If this is the case, it will stop transmission of its own message. This is very important in the case of motor vehicle data transmission.

Errors in a message are recognised by what is known as a CRC. This is an error detection scheme in which all the bits in a block of data are divided by a predetermined binary number. A check character, known to the transmitter and receiver, is determined by the remainder. If an error is recognised, the message on the bus is destroyed. This in turn is recognised by the transmitter, which then sends the message again. This technique, when combined with additional tests, makes it possible to discover all faulty messages.

The CRC f eld is part of the overall message. (The basic idea behind CRCs is to treat the message string as a single binary word M, and divide it by a keyword k that is known to both the transmitter and the receiver. The remainder r left after dividing M by k constitutes the 'check word' for the given message. The transmitter sends both the message string M and the check word r, and the receiver can then check the data by repeating the calculation, dividing M by the keyword k, and verifying that the remainder is r.)

Because each node in effect monitors its own output, interrupts disturbed transmissions, and acknowledges correct transmissions, faulty stations can be recognised and uncoupled (electronically) from the bus. This prevents other transmissions from being disturbed.

A CAN message may vary between 44 and 108 bits in length. This is made up of a start bit, name, control bits, the data itself, CRC error detection, a conf rmation signal and f nally a number of stop bits.

Def nition

The cyclic redundancy check (CRC) f eld is part of the overall message. (The basic idea behind CRCs is to treat the message string as a single binary word M, and divide it by a keyword k that is known to both the transmitter and the receiverThe remainder r left after dividing M by k constitutes the 'check word' for the given message. The transmitter sends both the message string M and the check word r and the receiver can then check the data by repeating the calculation, dividing M by the keyword k, and verifying that the remainder is.)r

8.2.4 Local interconnect network

A local interconnect network (LIN) is a serial bus system especially suited for networking 'intelligent' devices, sensors and actuators within a sub-system. It is a concept for low-cost automotive networks, which complements existing automotive multiplex networks such as CAN.

Key fact

LIN is a concept for low-cost automotive networks, which complements existing automotive multiplex networks such as CAN.

LIN enables the implementation of a hierarchical vehicle network. This allows further quality enhancement and cost reduction of vehicles (Figure 8.12).

The LIN standard includes the specif cation of the transmission protocol, the transmission medium, the interface between development tools, and the interfaces for software programming. LIN guarantees the interoperability of network nodes from the viewpoint of hardware and software, and predictable electromagnetic compatibility (EMC) behaviour (Figure 8.13).

LIN is a time-triggered single-master, multiple-slave network concept. It is based on common interface hardware, which makes it a low-cost solution. Additional attributes of LIN are

- multicast reception with self-synchronisation;
- selectable length of message frames;
- data checksum security and error detection;
- single-wire implementation;
- speed up to 20 kbit/s.

LIN provides a cost-eff cient bus communication where the bandwidth and versatility of CAN are not required. It is used for non-critical systems.

Def nition

EMC: Electromagnetic compatibility EMC requirements stipulate that a device shall not cause interference within itself or in other devices, or be susceptible to interference from other devices.

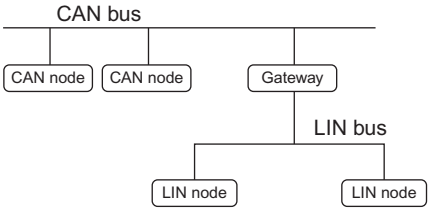


Figure 8.12 Structure using CAN and LIN

Key fact

FlexRay can cope with the requirements of X-by-wire systems.

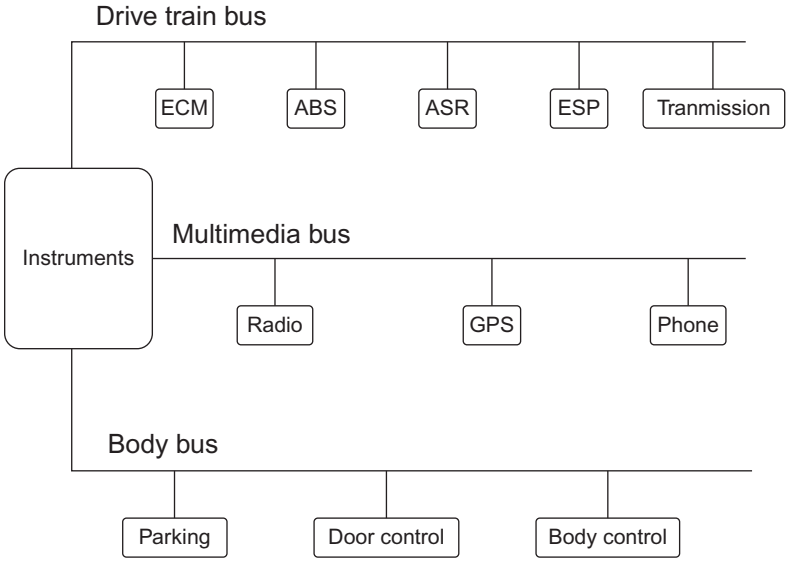


Figure 8.13 Standards allow communication between different systems

8.2.5 FlexRay



Figure 8.14 FlexRay logo

FlexRay is a fast and fault-tolerant bus system for automotive use. It was developed, using the experience of well-known original equipment manufactures (OEMs). It is designed to meet the needs of current and future in-car control applications that require a high bandwidth. The bit rate for FlexRay can be programmed to values up to 10 Mbit/s (Figure 8.14).

The data exchange between the control devices, sensors and actuators in automobiles is mainly carried out via CAN systems. However, the introduction of X-by-wire systems has resulted in increased requirements. This is especially so with regard to error tolerance and speed of message transmission. FlexRay meets these requirements by message transmission in f xed time slots, and by fault-tolerant and redundant message transmission on two channels (Figure 8.15).

The physical layer means the hardware, that is, the actual components and wires. FlexRay works on the principle of time division multiple access (TDMA). This means that components or messages have f xed time slots in which they have exclusive access to the data bus. These time slots are repeated in a cycle and are just a few milliseconds long.

FlexRay communicates via two physically separated lines with a data rate of up to 10 Mbit/s on each. The two lines are mainly used for redundant and therefore fault-tolerant message transmission, but they can also transmit different messages.

Key fact

FlexRay communicates via two physically separated lines with a data rate of up to 10 Mbit/s on each.

FlexRay is a fast and fault-tolerant bus system that was developed to meet the needs of high bandwidth applications such as X-by-wire systems. Error tolerance and speed of message transmission in these systems is essential (Figure 8.16).

8.3 Diagnostics – multiplexing

The integrity of the signal on the CAN can be checked in two ways. The f rst way is to examine the signal on a dual-channel scope connected to the CAN-high and CAN-low lines (Figure 8.17).

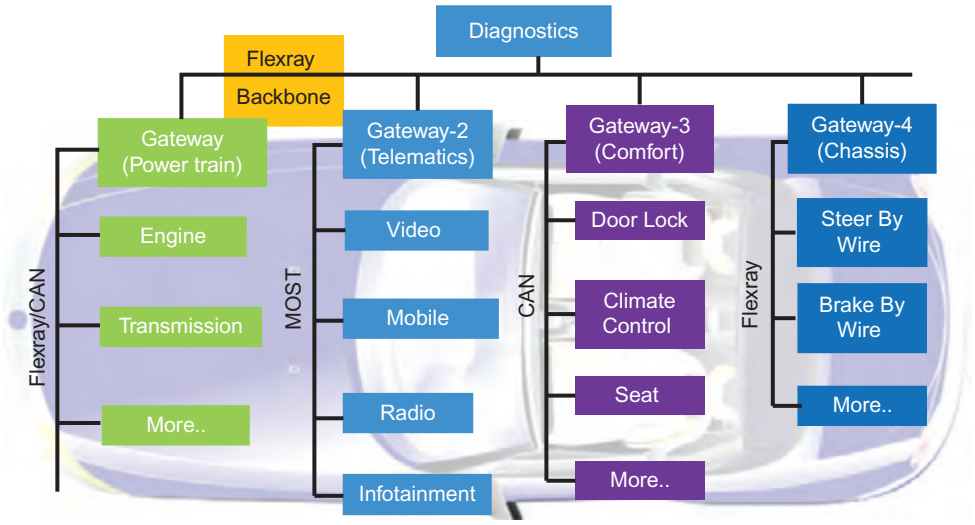


Figure 8.15 FlexRay backbone

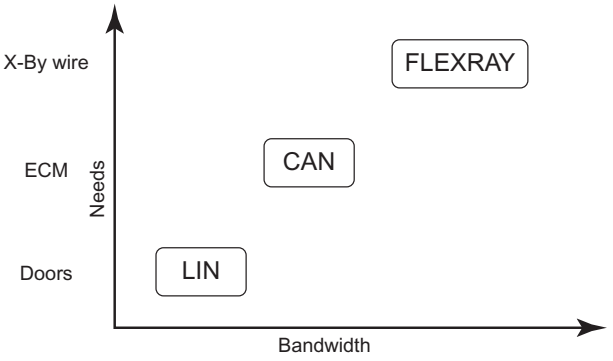


Figure 8.16 Comparing requirements and data rates of the three systems

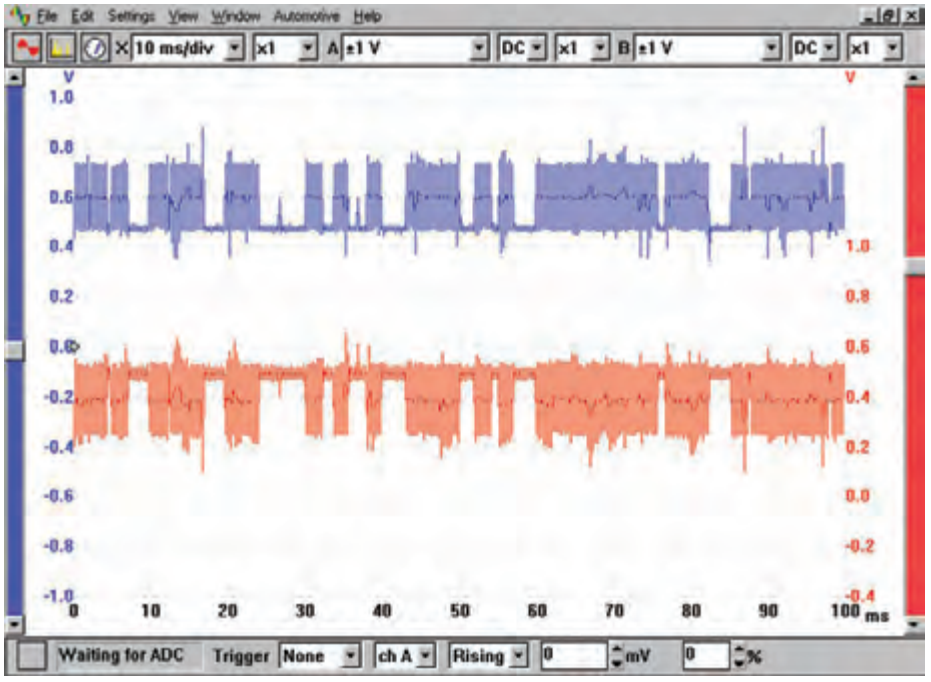


Figure 8.17 CAN signals

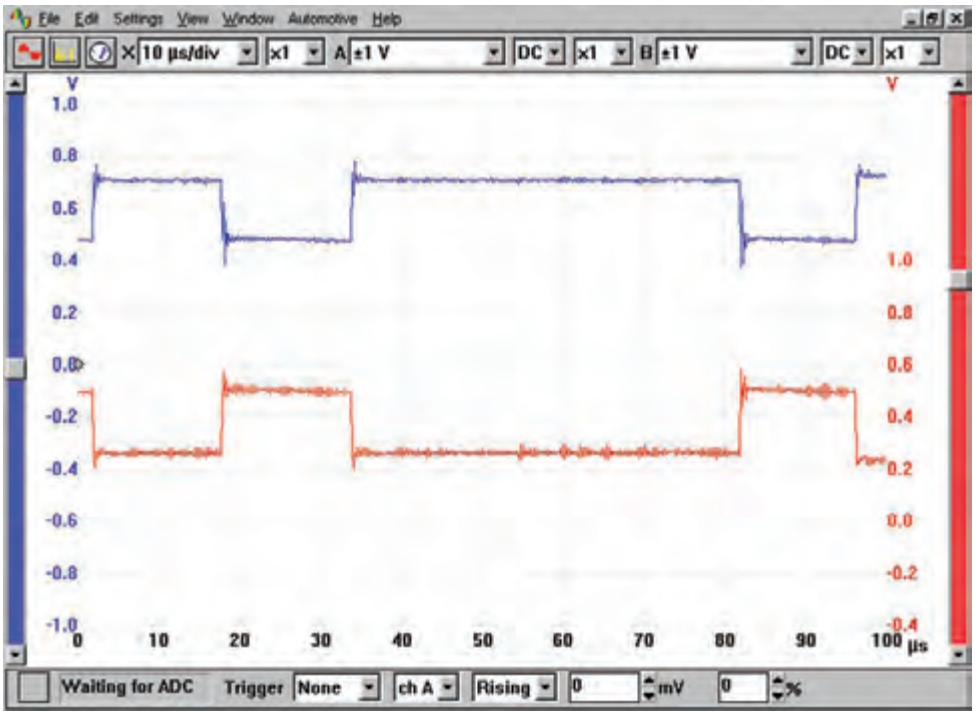


Figure 8.18 CAN signals on a fast timebase

In this display, it is possible to verify that

- data is being continuously exchanged along the CAN bus;
- the voltage levels are correct;
- a signal is present on both CAN lines.

Key fact

CAN uses a differential signal, so the signal on one line should be a coincident mirror image of the data on the other line.

CAN uses a differential signal, so the signal on one line should be a coincident mirror image of the data on the other line. The usual reasons for examining the CAN signals is where a CAN fault has been indicated by OBD, or to check the CAN connection to a suspected faulty CAN node. Manufacturers' data should be referred to for precise waveform parameters.

The following CAN data is captured on a much faster timebase and allows the individual state changes to be examined (Figure 8.18). This enables the mirror image nature of the signals, and the coincidence of the edges to be verif ed.

The signals are equal and opposite and they are of the same amplitude (voltage). The edges are clean and coincident with each other. This shows that the vehicle data bus (CAN bus) is enabling communication between the nodes and the CAN controller unit. This test effectively verif es the integrity of the bus at this point in the network. If a particular node is not responding correctly, the fault is likely to be the node itself. The rest of the bus should work correctly.

It is usually recommended to check the condition of the signals present at the connector of each of the ECUs on the network. The data at each node will always be the same on the same bus. Remember that much of the data on the bus is safety critical, so do *not* use insulation piercing probes!

PicoTech have produced the CAN test box. This gives easy access to the 16 pins of the diagnostic connector that is f tted to all modern vehicles. Depending on the conf guration of the vehicle, this may allow you to check power, ground and CAN bus signal quality (Figure 8.19).

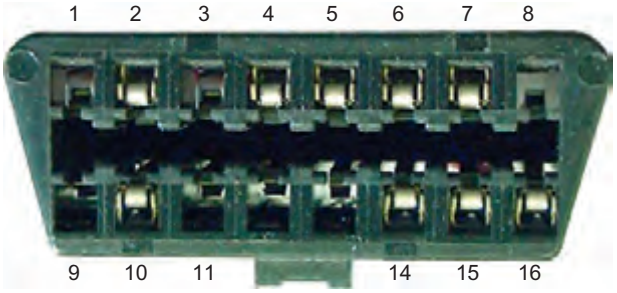


Figure 8.19 16 Pin data link connector

Connector design and location is dictated by an industry wide (OBD2) standard. Vehicle manufacturers can use the empty DLC terminals for whatever they would like. However, the DLC of every vehicle is required to provide pins 4 and 5 and 16 as def ned below. Further, after the CAN protocol was fully implemented in the 2008 model year, all vehicles must use pins 6 and 14 as def ned below:

- Terminal 2 – SAE J1850 10.4 kbits/s (kbps) variable pulse width serial data (GM Class-2) or SAE J1850 41.6 kbps pulse width modulation serial data high line (Ford)
- Terminal 4 – Scan tool chassis ground
- Terminal 5 – Common signal ground for serial data lines (Logic Low)
- Terminal 6 – ISO 11898/15765/SAE J2284 CAN serial data high line
- Terminal 7 – ISO 9141 K serial data line or ISO 14230 (Keyword 2000) serial data line (DaimlerChrysler/Honda/Toyota)
- Terminal 10 – SAE J1850 41.6 kbps pulse width modulation serial data low line (Ford)
- Terminal 14 – ISO 11898/15765/SAE J2284 CAN serial data low line
- Terminal 15 – ISO 9141 L serial data line or ISO 14230 (Keyword 2000) serial data line (DaimlerChrysler/Honda)
- Terminal 16 – Scan tool power (unswitched battery positive voltage)

With the test leads supplied, a PicoScope automotive scope, or any other suitable scope may be connected to the CAN test box. This allows the monitoring of any signals present, such as CAN high and CAN low.

The CAN test box has a 2.5 m cable so that work can be carried out at a convenient location away from the diagnostic connector. An additional pass-through connector allows a scan tool to be connected at the same time as a scope. Its 4-mm sockets are backlit by LEDs to show the state of each pin on the connector. The CAN test box is powered by the diagnostic connector, so batteries or a mains adaptor are not needed (Figure 8.20).

In the two CAN scope patterns shown previously, the second is on a timebase 1000 times faster than the f rst so that more details of the signal are shown. The connection for one of the traces is to pin 6 and the other to pin 14.

The second way of checking the CAN signals is to use a suitable reader or scanner.

The KTS 200 controller diagnostic tester from Bosch is a good example of and OBD/CAN reader as it offers a wide range of features (Figure 8.21). It reads diagnostic codes and CAN data. The device can be used both as a full controller diagnostic tester, complete with a testing scope, and for straightforward servicing work on vehicles.



Figure 8.20 CAN test box (Source: PicoTech)



Figure 8.21 KTS 200 kit

It is powered via the diagnostic cable, the cigarette lighter cable or a power pack.

OBD has been in use for some time in its different formats. However, the CAN protocol is a popular standard and is making signif cant in-roads into the market. Since 2008, all vehicles sold in the European Union and United States are required to have implemented CAN. This should f nally eliminate the ambiguity of the several existing signalling protocols (Figure 8.22).

Key fact

Since 2008, all vehicles sold in the European Union and United States are required to have implemented CAN.

8.4 Lighting

8.4.1 External lights

Figure 8.23 shows the rear lights of a modern car. Note how in common with many manufacturers, the lenses are almost smooth and clear. This is because



Figure 8.22 OBD connector on a BMW



Figure 8.23 BMW rear lights

the ref ectors now carry out diffusion of the light. Regulations exist relating to external lights. Table 8.2 is a simplif ed interpretation of current rules.

Key fact

LED lights are now allowed and are specif ed by light output rather than wattage.

8.4.2 Lighting circuits

Figure 8.24 shows a simplif ed lighting circuit. While this representation helps to demonstrate the way in which a lighting circuit operates, it is not now used in this simple form. The circuit does, however, help to show in a simple way how various lights in and around the vehicle operate with respect to each other. For example, fog lights can be wired to work only when the side lights are on. Another example is how the headlights cannot be operated without the side lights f rst being switched on.

Table 8.2 Lighting features

Sidelights	A vehicle must have two sidelights each with wattage of less than 7W. Most vehicles have the sidelight incorporated as part of the headlight assembly
Rear lights	Again two must be fitted each with wattage not less than 5W. Lights used in Europe must be 'E' marked and show a diffused light. Position must be within 400 mm from the vehicle edge and over 500 mm apart and between 350 and 1500 mm above the ground
Brake lights	Two lights often combined with the rear lights. They must be between 15 and 36 W each, with diffused light, and must operate when any form of the brake is applied. Brake lights must be between 350 and 1500 mm above the ground and at least 500 mm apart in a symmetrical position. High-level brake lights are now allowed, and if fitted, must operate with the primary brake lights
Reverse lights	No more than two lights may be fitted with a maximum wattage each of 24 W. The light must not dazzle and either be switched automatically from the gearbox or with a switch incorporating a warning light. Safety reversing 'beepers' are now often fitted in conjunction with this circuit, particularly on larger vehicles
Day running lights	Volvo use day running lights as these are in fact required in Sweden and Finland. These lights come on with the ignition and must only work in conjunction with the rear lights. Their function is to indicate that the vehicle is moving or about to move. They switch off when parking or headlights are selected
Rear fog lights	One or two may be fitted, but if only one, it must be on the offside or centre line of the vehicle. They must be between 250 and 1000 mm above the ground and over 100 mm from any brake light. The wattage is normally 21 W and they must only operate when either the side lights, headlights or front fog lights are in use
Front spot and fog lights	If front spot lights are fitted (auxiliary driving lights), they must be between 500 and 1200 mm above the ground and more than 400 mm from the side of the vehicle. If the lights are non-dipping, then they must only operate when the headlights are on main beam. Front fog lamps are fitted below 500 mm from the ground and may only be used in fog or falling snow. Spot lamps are designed to produce a long beam of light to illuminate the road in the distance. Fog lights are designed to produce a sharp cut-off line such as to illuminate the road just in front of the vehicle but without dazzling oncoming or causing glare

Safety first

Note: If there is any doubt as to the visibility or conditions, switch on dipped headlights. If your vehicle is in good order, it will not discharge the battery.

Dim dip headlights were an attempt to stop drivers just using side lights in semi-dark or poor visibility conditions. The circuit is such that when side lights and ignition are on together, then the headlights will come on automatically at about one-sixth of normal power.

Dim dip lights are achieved in one of two ways. The first uses a simple resistor in series with the headlight bulb and the second is to use a 'chopper' module which switches the power to the headlights on and off rapidly. In either case, the 'dimmer' is bypassed when the driver selects normal headlights. The most cost-effective method is using a resistor, but this has the problem that the resistor (approximately 1 Ω) gets quite hot and hence has to be positioned appropriately. Figure 8.25 shows a typical vehicle lighting circuit.

8.4.3 Gas discharge lighting

Xenon gas discharge headlamps (GDL) are now fitted to some vehicles. They have the potential to provide more effective illumination and new design possibilities for the front of a vehicle. The conflict between aerodynamic

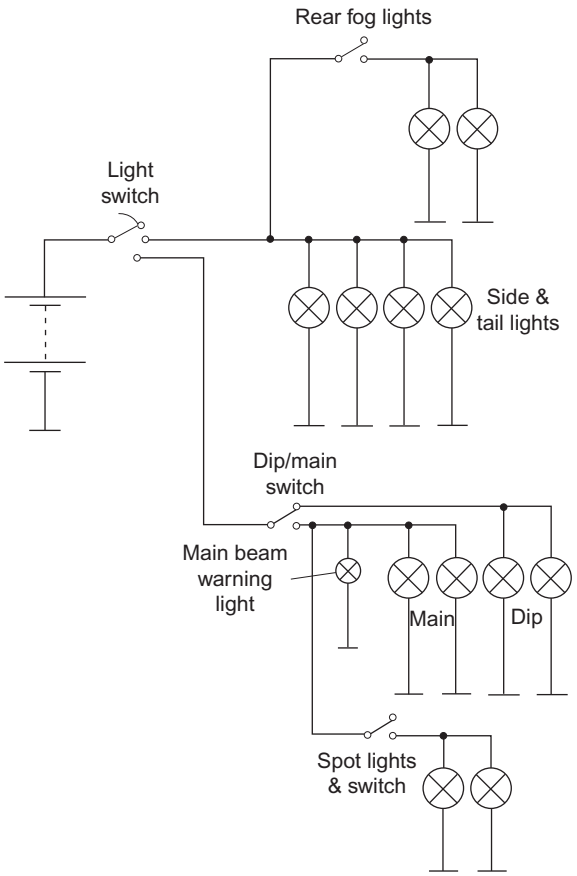


Figure 8.24 Simplified lighting circuit

styling and suitable lighting positions is an economy/safety trade off, which is undesirable. The new headlamps make a significant contribution towards improving this situation because they can be relatively small. The GDL system consists of three main components:

- Bulb – this operates in a very different way from conventional incandescent bulbs. A much higher voltage is needed.
- Ballast system – this contains an ignition and control unit and converts the electrical system voltage into the operating voltage required by the lamp. It controls the ignition stage and run up as well as regulating during continuous use and finally monitors operation as a safety aspect.
- Headlamp – the design of the headlamp is broadly similar to conventional units. However, in order to meet the limits set for dazzle, a more accurate finish is needed and hence more production costs are involved.

8.4.4 LED lighting

The advantages of LED lighting are clear, the greatest being reliability. LEDs have a typical rated life of over 50 000 hours compared to just a few thousand for incandescent lamps. The environment in which vehicle lights have to survive is hostile to say the least. Extreme variations in temperature and humidity as well as serious shocks and vibration have to be endured.

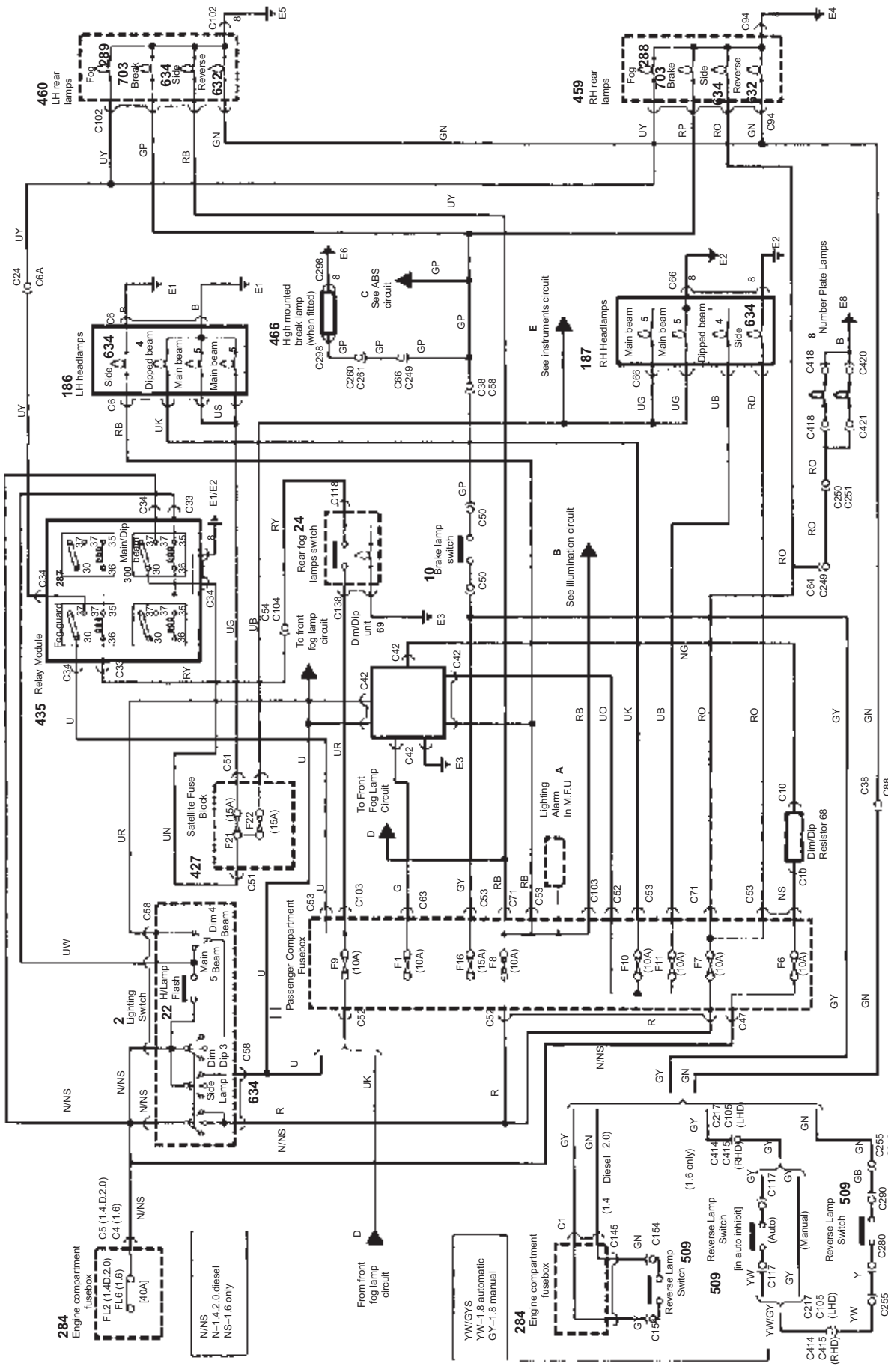


Figure 8.25 Complete lighting circuit



Figure 8.26 Xenon lighting



Figure 8.27 Adaptive lighting using LEDs

Key fact

LEDs have a typical rated life of over 50000 hours compared to just a few thousand for conventional lamps, which must make them incandescent.

LEDs are more expensive than bulbs but the potential savings in design costs due to sealed units being used and greater freedom of design could outweigh the extra expense. A further advantage is that they turn on quicker than ordinary bulbs. This time is approximately the difference between 130 ms for the LEDs and 200 ms for bulbs. If this is related to a vehicle brake light at motorway speeds, then the increased reaction time equates to about a car length. This is potentially a major contribution to road safety. LEDs as high-level brake lights are becoming popular because of the shock resistance, which will allow them to be mounted on the boot lid (Figures 8.26 and 8.27).

Heavy vehicle side marker lights are an area of use where LEDs have proved popular. Many lighting manufacturers are already producing lights for the aftermarket. Being able to use sealed units will greatly increase the life expectancy. Side indicator repeaters are a similar issue due to the harsh environmental conditions.

8.5 Diagnostics – lighting

8.5.1 Testing procedure

The process of checking a lighting system circuit is broadly presented in Figure 8.28.

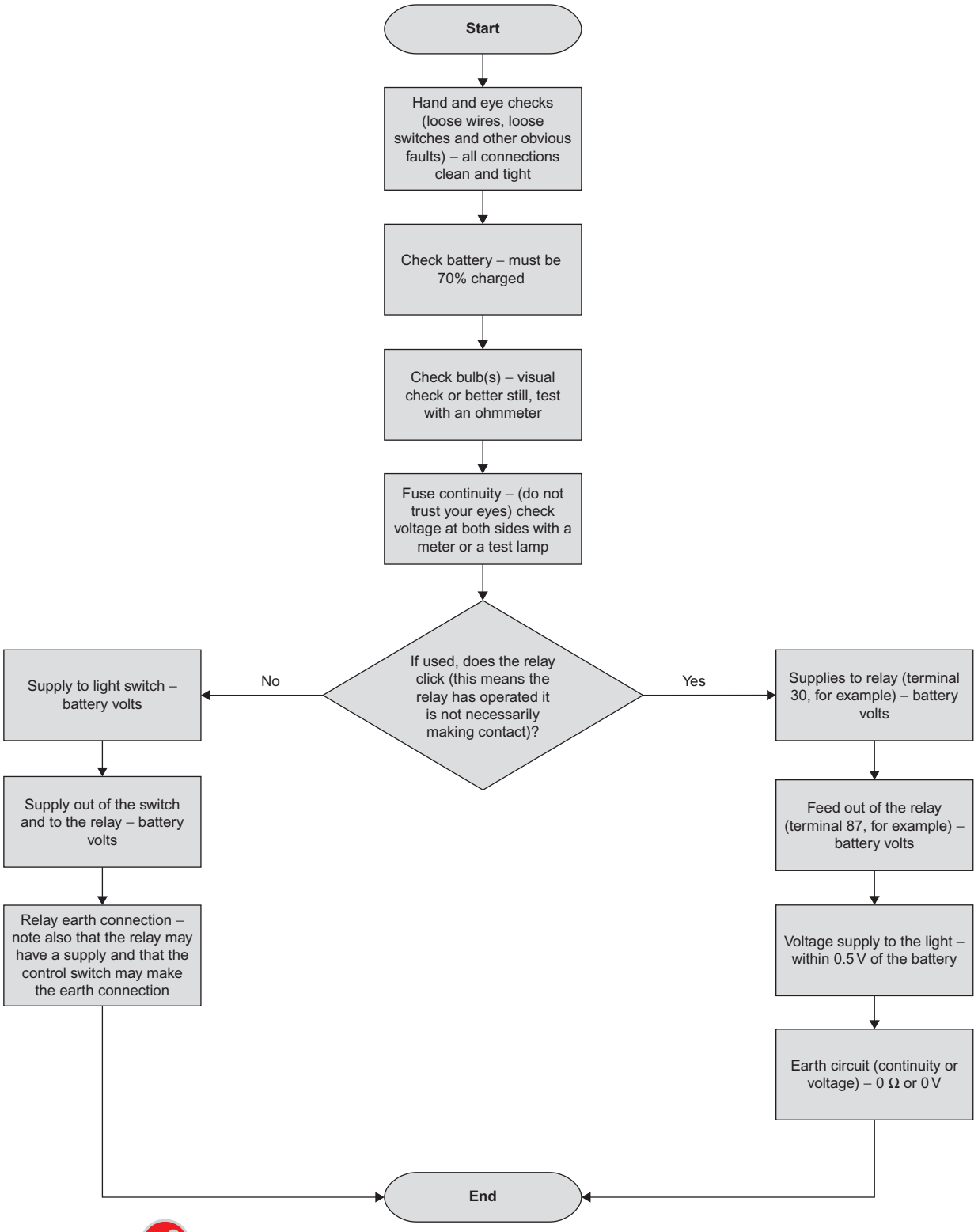


Figure 8.28 Lighting system diagnostics chart

Key fact

A circuit should be able to supply a minimum of 95% of the available battery voltage to the consumers (bulbs, etc.).

Figure 8.29 shows a simplif ed dim dip lighting circuit with meters connected for testing. A simple principle to keep in mind is that the circuit should be able to supply all the available battery voltage to the consumers (bulbs, etc.). A loss of 5% may be acceptable.

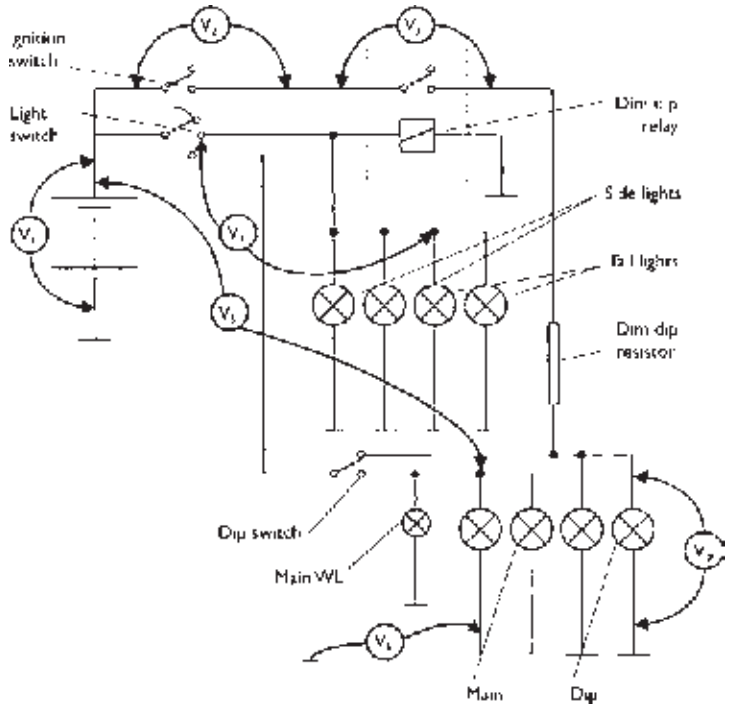


Figure 8.29 Lighting circuit under test

With all the switches in the 'on' position appropriate to where the meters are connected, the following readings should be obtained:

- V1 12.6 V (if less, check battery condition);
- V2 0–0.2 V (if more, the ignition switch contacts have a high resistance);
- V3 0–0.2 V (if more, the dim dip relay contacts have a high resistance);
- V4 0–0.2 V (if more, there is a high resistance in the circuit between the output of the light switch and the junction for the tail lights);
- V7 12–12.6 V if on normal dip or approximately 6 V if on dim dip (if less, then there is a high resistance in the circuit – check other readings, etc., to narrow down the fault).

8.5.2 Lighting fault diagnosis table

Symptom	Possible fault
Lights dim	High resistance in the circuit Low alternator output Discoloured lenses or reflectors
Headlights out of adjustment	Suspension fault Loose fittings Damage to body panels Adjustment incorrect
Lights do not work	Bulbs blown Fuse blown Loose or broken wiring/connections/fuse Relay not working Corrosion in light units Switch not making contact



Figure 8.30 Headlights



Figure 8.31 Headlamp alignment(Source: Hella)

8.5.3 Headlight beam setting

Many types of beam-setting equipment are available and most work on the same principle. The method is the same as using an aiming board but is more convenient and accurate due to easier working and because less room is required.

Move the beam setter into position in front of the headlamp to be checked, and align the beam setter box with the middle of the headlamp (Figures 8.30 and 8.31). It must not be more than 3 cm out of line horizontally or vertically. The distance between the front edge of beam setter box and the headlamp should

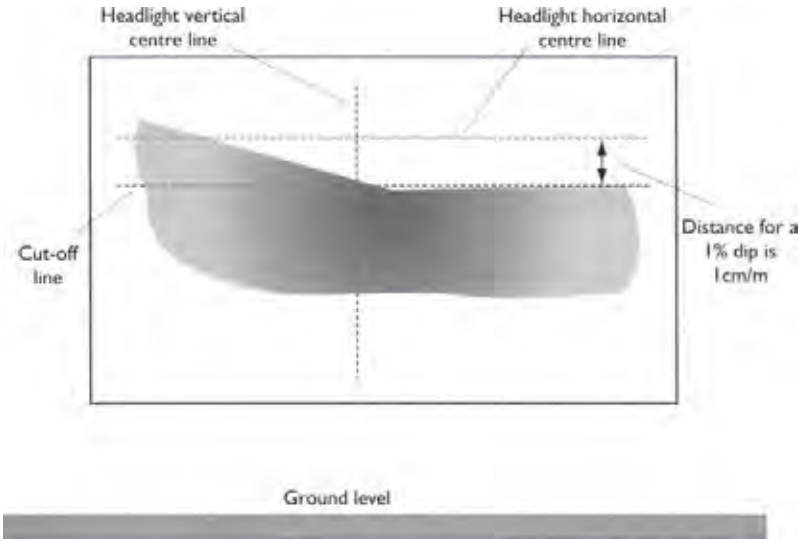


Figure 8.32 Asymmetric dip beam pattern

be between 30 and 70 cm. The beam setter must be re-adjusted before each headlamp is checked.

When adjusting the headlamps, the given inclination for the cut-off line (from a data book, etc.) must be set on the alignment equipment. The beam is now adjusted until the cut-off line and break off are in the correct position on the screen of the aligner.

To set the headlights of a car using an aiming board, the following procedure should be adopted.

1. Park the car on level ground square onto a vertical aiming board at a distance of 10 m, if possible. The car should be unladen except for the driver.
2. Mark out the aiming board as shown in Figure 8.32.
3. Bounce the suspension to ensure it is level.
4. With the lights set on dip beam, adjust the cut-off line to the horizontal mark, which will in most cases be 1 cm below the height of the headlight centre for every 1 m the car is away from the board*. The break-off point should be adjusted to the centre line of each light in turn.

Note: If the required dip is 1% then 1 cm* per 1 m. If 1.2% is required, then 1.2 cm per 1 m, etc. Always check data for actual settings.

8.6 Auxiliaries

8.6.1 Wiper motors and linkages

Most wiper linkages consist of series or parallel mechanisms. Some older types use a f exible rack and wheel boxes similar to the operating mechanism of many sunroofs. One of the main considerations for the design of a wiper linkage is the point at which the blades must reverse, because of the high forces on the motor and linkage at this time. If the reverse point is set so that the linkage is at its maximum force transmission angle, then the reverse action of the blades puts less strain on the system. This also ensures smoother operation (Figure 8.33).

Key fact

Most wiper linkages consist of series or parallel mechanisms.

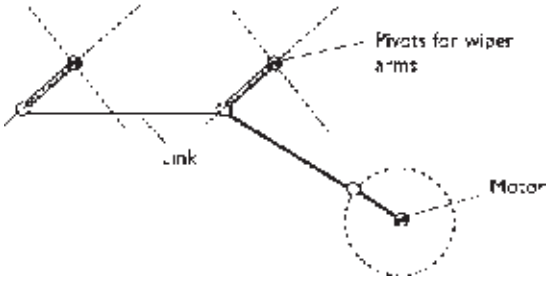


Figure 8.33 Wiper linkage

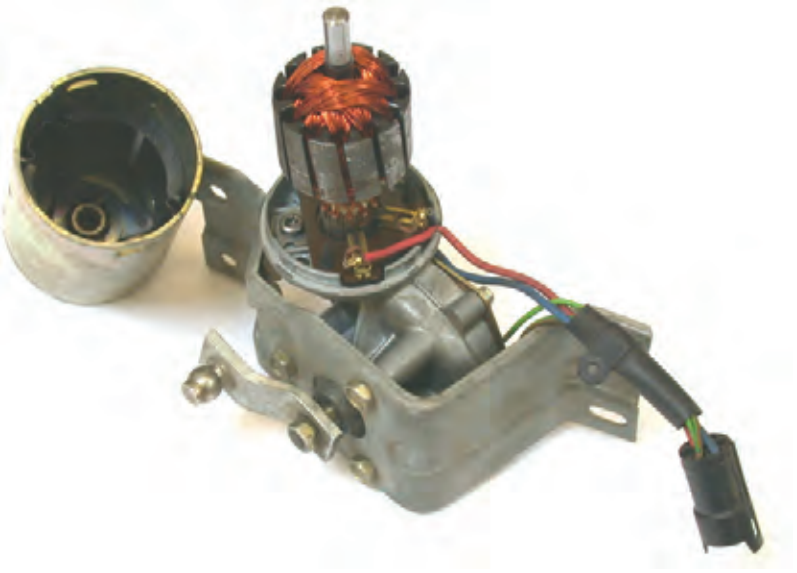


Figure 8.34 Wiper motor using three brushes for two-speed operation

Most if not all wiper motors now in use are permanent magnet motors. The drive is taken via a worm gear to increase torque and reduce speed. Three brushes may be used to allow two-speed operation. The normal speed operates through two brushes placed in the usual positions opposite to each other. For a fast speed, the third brush is placed closer to the earth brush. This reduces the number of armature windings between them, which reduces resistance, hence increasing current and therefore speed. Typical specif cations for wiper motor speed and hence wipe frequency are 45 rpm at normal speed and 65 rpm at fast speed. The motor must be able to overcome the starting friction of each blade at a minimum speed of 5 rpm (Figure 8.34).



Figure 8.35 Wiper motor

The wiper motor or the associated circuit often has some kind of short circuit protection (Figure 8.35). This is to protect the motor in the event of stalling, if frozen to the screen, for example. A thermal trip of some type is often used or a current sensing circuit in the wiper ECU if f tted.

The windscreen washer system usually consists of a simple DC permanent magnet motor driving a centrifugal water pump. The water, preferably with a cleaning additive, is directed onto an appropriate part of the screen by two or more jets. A non-return valve is often f tted in the line to the jets to prevent water siphoning back to the reservoir. This also allows ‘instant’ operation when the washer button is pressed. The washer circuit is normally linked in to the wiper

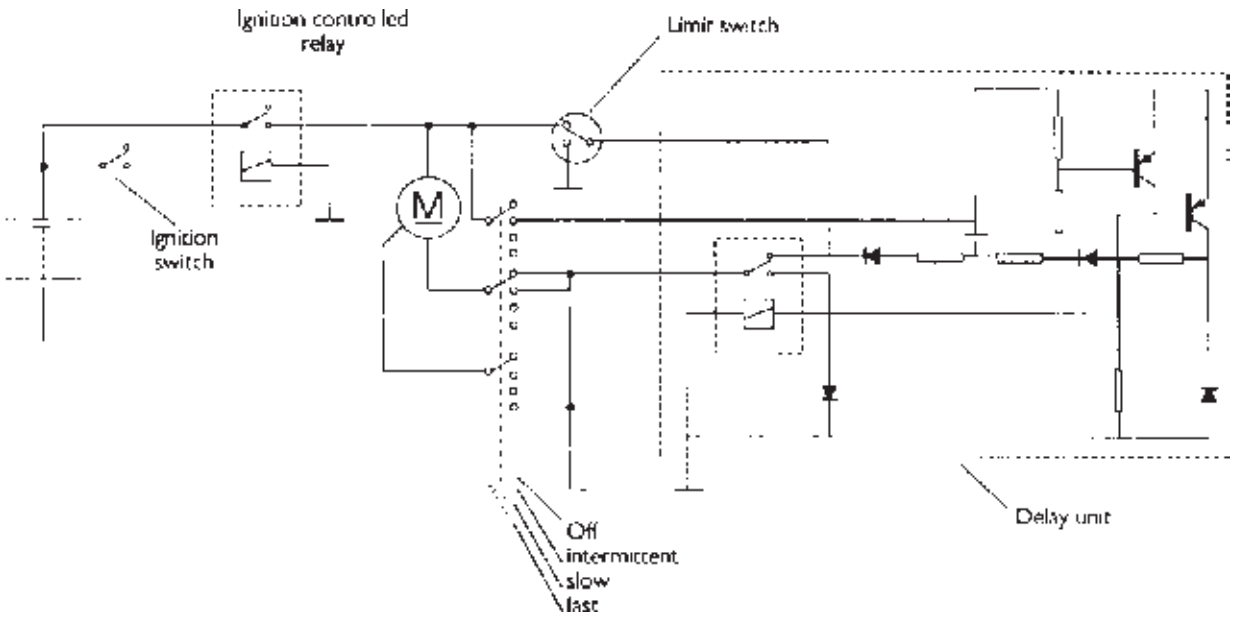


Figure 8.36 Traditional wiper circuit

circuit such that when the washers are operated the wipers start automatically and will continue for several more sweeps after the washers have stopped.

8.6.2 Wiper circuits

Figure 8.36 shows a circuit for fast, slow and intermittent wiper control. The switches are shown in the off position and the motor is stopped and is in its park position. Note that the two main brushes of the motor are connected together via the limit switch, delay unit contacts and the wiper switch. This causes regenerative braking because of the current generated by the motor due to its momentum after the power is switched off. Being connected to a very low resistance loads up the 'generator' and it stops instantly when the park limit switch closes.

When either the delay contacts or the main switch contacts are operated, the motor will run at slow speed. When fast speed is selected, the third brush on the motor is used. On switching off, the motor will continue to run until the park limit switch changes over to the position shown. This switch is only in the position shown when the blades are in the parked position.

Many vehicles use a system with more enhanced facilities. This is regulated by, what may be known as, a central control unit (CCU), a multi-function unit (MFU) or a general electronic module (GEM). These units often control other systems as well as the wipers, thus allowing reduced wiring bulk under the dash area. Electric windows, headlights and heated rear window, to name just a few, are now often controlled by a central unit (Figure 8.37).

Using electronic control, a CCU allows the following facilities for the wipers:

- front and rear wash/wipe;
- intermittent wipe;
- time delay set by the driver;
- reverse gear selection rear wipe operation;

Key fact

A central control unit (CCU), a multi-function unit (MFU) or a general electronic module (GEM) is now often used to control a range of auxiliary components.

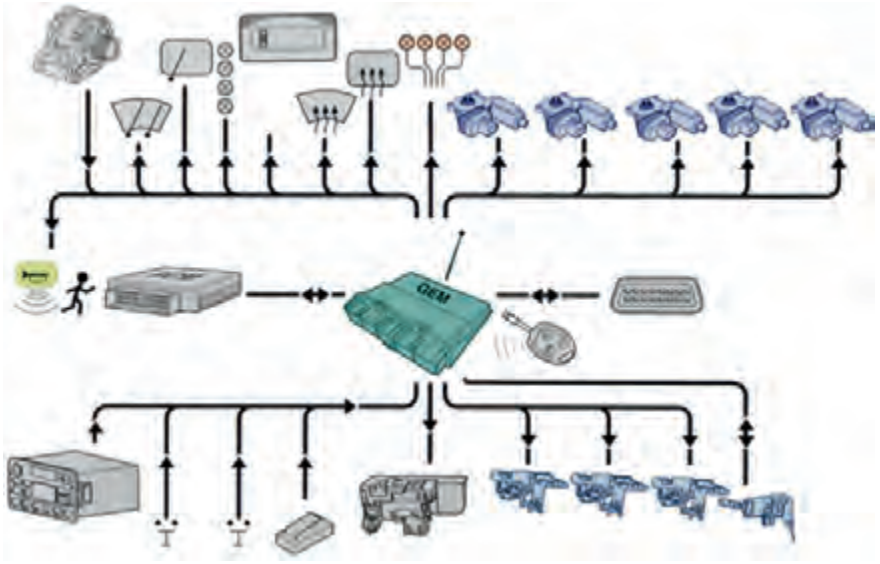


Figure 8.37 GEM and components(Source: Ford Motor Company)

- rear wash/wipe with 'dribble wipe' (an extra wipe several seconds after washing);
- stall protection.

8.6.3 Two-motor wiper system

More and more carmakers are exploiting the advantages of the two-motor wiper systems where each of the wiper arms is driven by its own electric motor. The advantage is the largest possible wiped area, yet they are compact in construction. This system is f tted, for example, in the new Ford Galaxy, as well as in the recently launched Mercedes-Benz S-Class.

Key fact

The two-motor wiper system synchronises its two drives electronically.

The two-motor wiper system synchronises its two drives entirely electronically (Figure 8.38). Integrated sensors continuously monitor the precise position of the wiper arms. This allows the change in direction to be individually determined; the change can, therefore, always take place very close to the A-pillar, which provides the widest possible f eld of view under all conditions. When the wiper is switched off, the wiper arms and blades can disappear completely under the engine bonnet/hood. This improves aerodynamics and reduces the risk of injury to pedestrians and cyclists in the event of an accident. It is also possible for the wiper equipment to work fully automatically when combined with the rain and light sensors.

At present, approximately 5% of all the cars manufactured in Europe are f tted with a two-motor wiper system. This proportion is expected to double over the next f ve years.

8.6.4 Headlight wipers and washers

There are two ways in which headlights are cleaned, f rst by high-pressure jets and second by small wiper blades with low-pressure water supply. The second



Figure 8.38 Two wiper motors must be synchronised (Source: Bosch Media)

method is in fact much the same as windscreen cleaning but on a smaller scale. The high-pressure system tends to be favoured but can suffer in very cold conditions due to the f uid freezing. It is expected that the wash system should be capable of approximately 50 operations before ref lling of the reservoir is necessary. Headlight cleaners are often combined with the windscreen washers. They operate each time the windscreen washers are activated, if the headlights are also switched on.

A retractable nozzle for headlight cleaners is often used. When the water pressure is pumped to the nozzle, it is pushed from its retracted position, f ush with the bodywork. When the washing is completed, the jet is then retracted back into the housing.

8.6.5 Indicators and hazard lights

Direction indicators have a number of statutory requirements. The light produced must be amber, but they may be grouped with other lamps. The f ashing rate must be between one and two per second with a relative 'on' time of between 30% and 57%. If a fault develops, this must be apparent to the driver by the operation of a warning light on the dashboard. The fault can be indicated by a distinct change in frequency of operation or the warning light remaining on. If one of the main bulbs fails then the remaining lights should continue to f ash perceptibly.

Key fact

Indicator fash rate must be between one and two per second with a relative 'on' time of between 30% and 57%.

Legislation as to the mounting position of the exterior lamps exists such that the rear indicator lights must be within a set distance of the tail lights and within a set height. The wattage of indicator light bulbs is normally 21 W at 6, 12 or 24 V as appropriate. Figure 8.39 shows a typical indicator and hazard circuit.

Flasher units are rated by the number of bulbs they are capable of operating. When towing a trailer or caravan, the unit must be able to operate at a higher wattage. Most units use a relay for the actual switching as this is not susceptible to voltage spikes and also provides an audible signal.

Key fact

Flasher units are rated by the number of bulbs they are capable of operating.

8.6.6 Brake lights

Most brake light circuits incorporate a relay to switch the lights, which is in turn operated by a spring-loaded switch on the brake pedal. Links from this circuit to

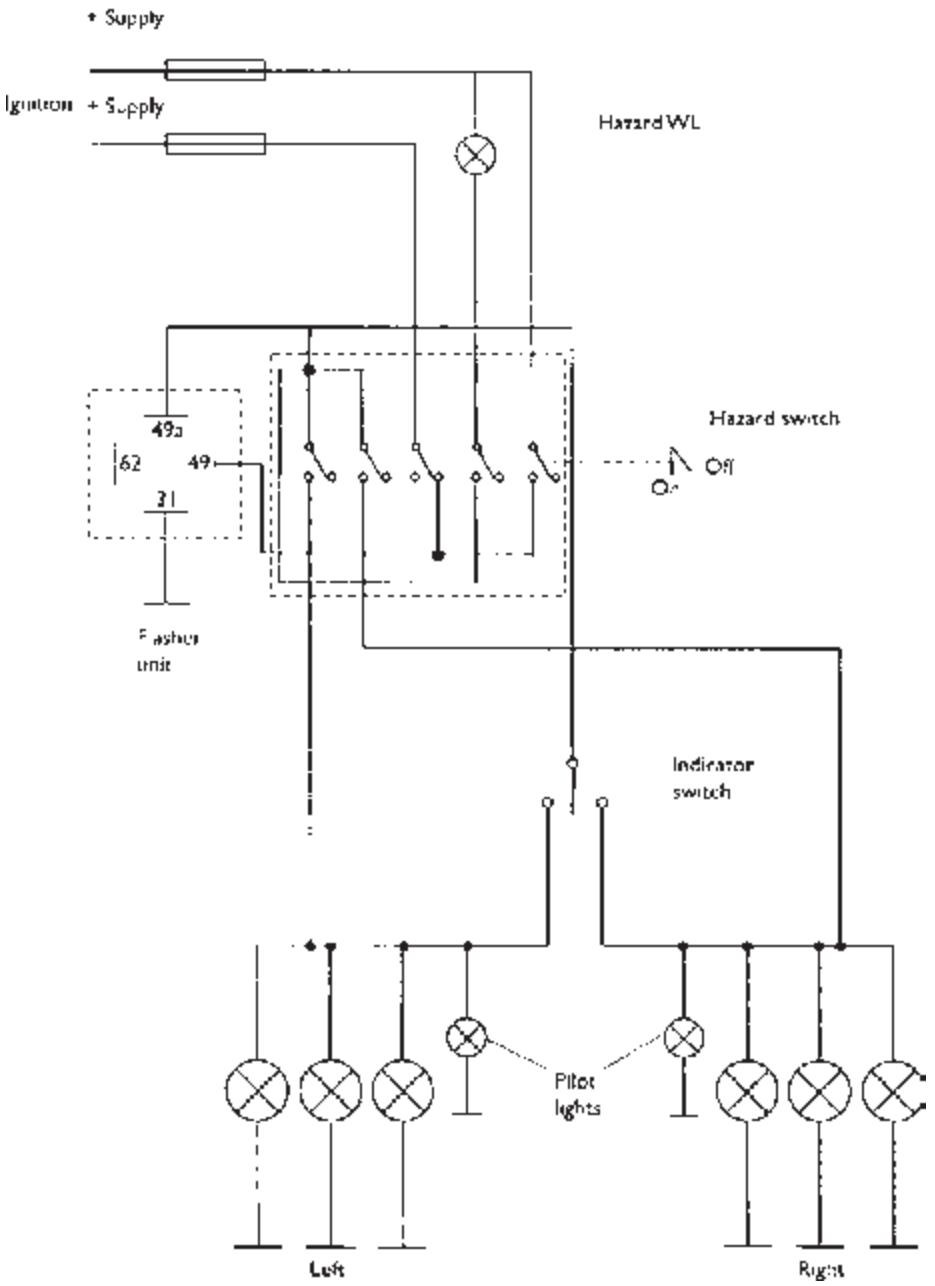


Figure 8.39 Indicator and hazard circuit

cruise control may be found. This is to cause the cruise control to switch off as the brakes are operated (Figure 8.40).

8.6.7 Electric horns

Regulations in most countries state that the horn (or audible warning device) should produce a uniform sound. This makes sirens and melody type fanfare horns illegal. Most horns draw a large current so are switched by a suitable relay.

The standard horn operates by simple electromagnetic switching. Current f ow causes an armature to which is attached a tone disc, to be attracted towards a stop. This opens a set of contacts which disconnects the current allowing the armature and disc to return under spring tension. The whole process keeps repeating when the horn switch is on. The frequency of movement and hence the fundamental tone is arranged to lie between 1.8 and 3.5 kHz. This note gives

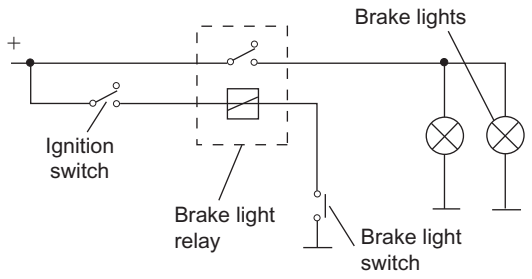


Figure 8.40 Simple relay operated circuit used for brake lights (stoplights)

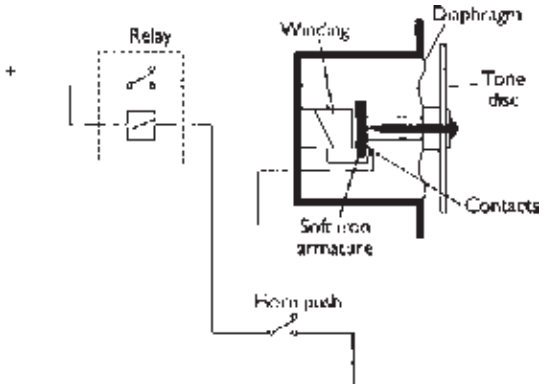


Figure 8.41 Typical horn together with its associated circuit



Figure 8.42 Engine cooling fan in position

good penetration through traff c noise. Twin horn systems, which have a high- and low-tone horn, are often used. This produces a more pleasing sound but is still very audible in both town and higher speed conditions (Figure 8.41).

8.6.8 Engine cooling fan motors

Most engine cooling fan motors (radiator cooling) are simple PM types. The fans used often have the blades placed asymmetrically (balanced but not in a regular pattern) to reduce noise when operating (Figure 8.42).

Key fact

The standard horn operates by simple electromagnetic switching.

Def nition

PM: Permanent magnet.

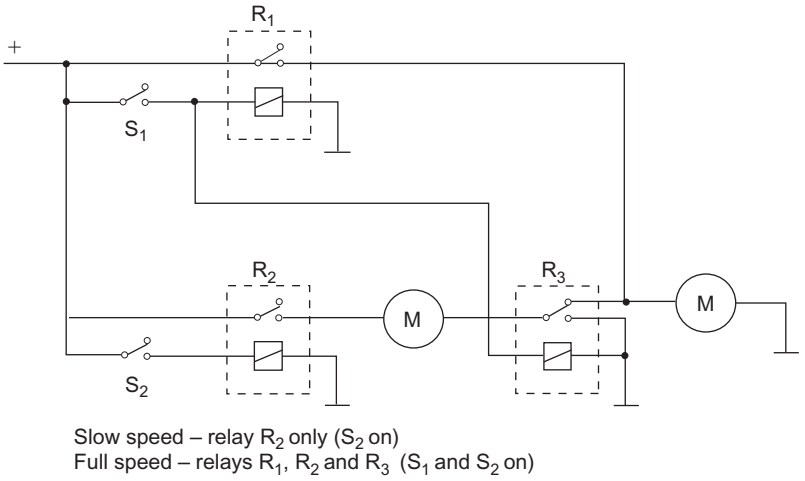


Figure 8.43 Two-speed, twin cooling fan circuit

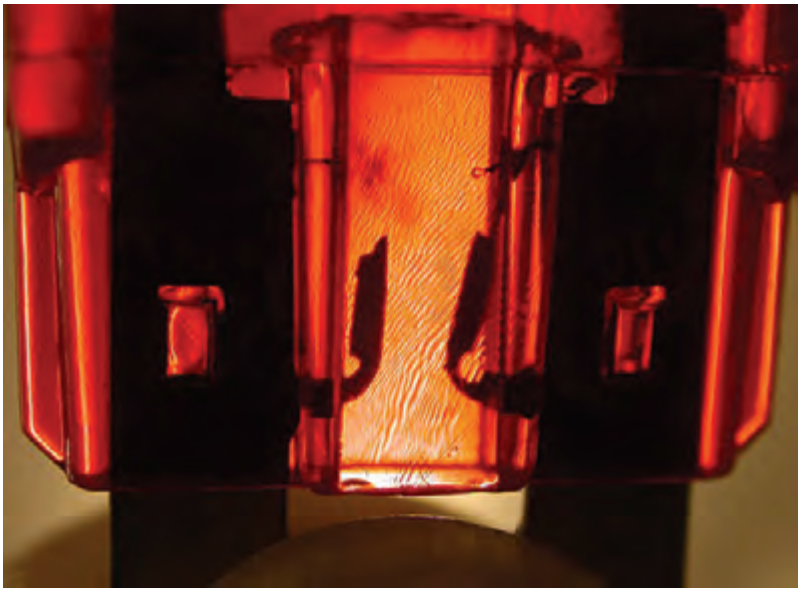


Figure 8.44 Remember to check the obvious first – like this blown fuse

When twin cooling fans and motors are fitted, they can be run in series or parallel. This is often the case when air conditioning is used as the condenser is usually placed in front of the radiator and extra cooling air speed may be needed. A circuit for series or parallel operation of cooling fans is shown above (Figure 8.43).

8.7 Diagnostics – auxiliary

8.7.1 Testing procedure

The process of checking an auxiliary system circuit is broadly as presented in Figure 8.45.

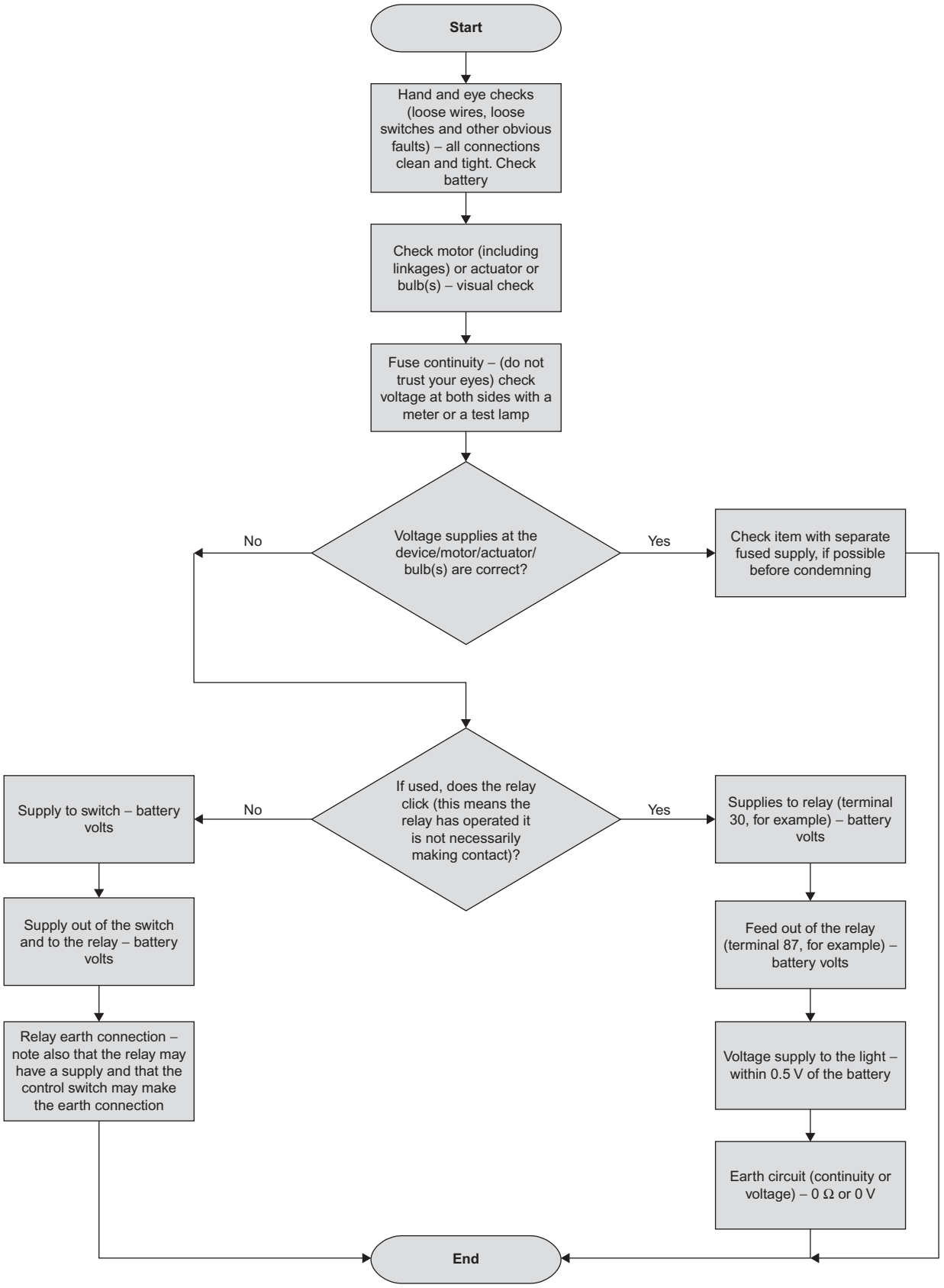


Figure 8.45 Auxiliary systems diagnosis chart

8.7.2 Auxiliaries fault diagnosis table

Symptom	Possible fault
Horn not working or poor sound quality	Loose or broken wiring/connections/fuse Corrosion in horn connections Switch not making contact High-resistance contact on switch or wiring Relay not working
Wipers not working or poor operation	Loose or broken wiring/connections/fuse Corrosion in wiper connections Switch not making contact High-resistance contact on switch or wiring Relay/timer not working Motor brushes or slip ring connections worn Limit switch contacts open circuit or high resistance Blades and/or arm springs in poor condition
Washers not working or poor operation	Loose or broken wiring/connections/fuse Corrosion in washer motor connections Switch not making contact Pump motor poor or not working Blocked pipes or jets Incorrect fuid additive used
Indicators not working or incorrect operating speed	Bulb(s) blown Loose or broken wiring/connections/fuse Corrosion in horn connections Switch not making contact High-resistance contact on switch or wiring Relay not working
Heater blower not working or poor operation	Loose or broken wiring/connections/fuse Switch not making contact Motor brushes worn Speed selection resistors open circuit

8.7.3 Wiper motor and circuit testing

Very modern wiper systems may need the assistance of a suitable scanner when diagnosing faults. However, don't forget the obvious tests such as correct voltage supplies, earth/ground connections and correct switch operation. All of which can be tested using a simple multimeter (Figure 8.46).

Figure 8.47 shows a procedure recommended by Lucas for testing an early type of wiper motor. The expected reading on the ammeter should not be more than approximately 5 A. Several types of wiper motor are in current use, so take care to make the appropriate connections for this test. Remember to use a fused jumper lead as a precaution.



Figure 8.46 Reversible wiper motor and drive linkage (Source: Bosch Media)

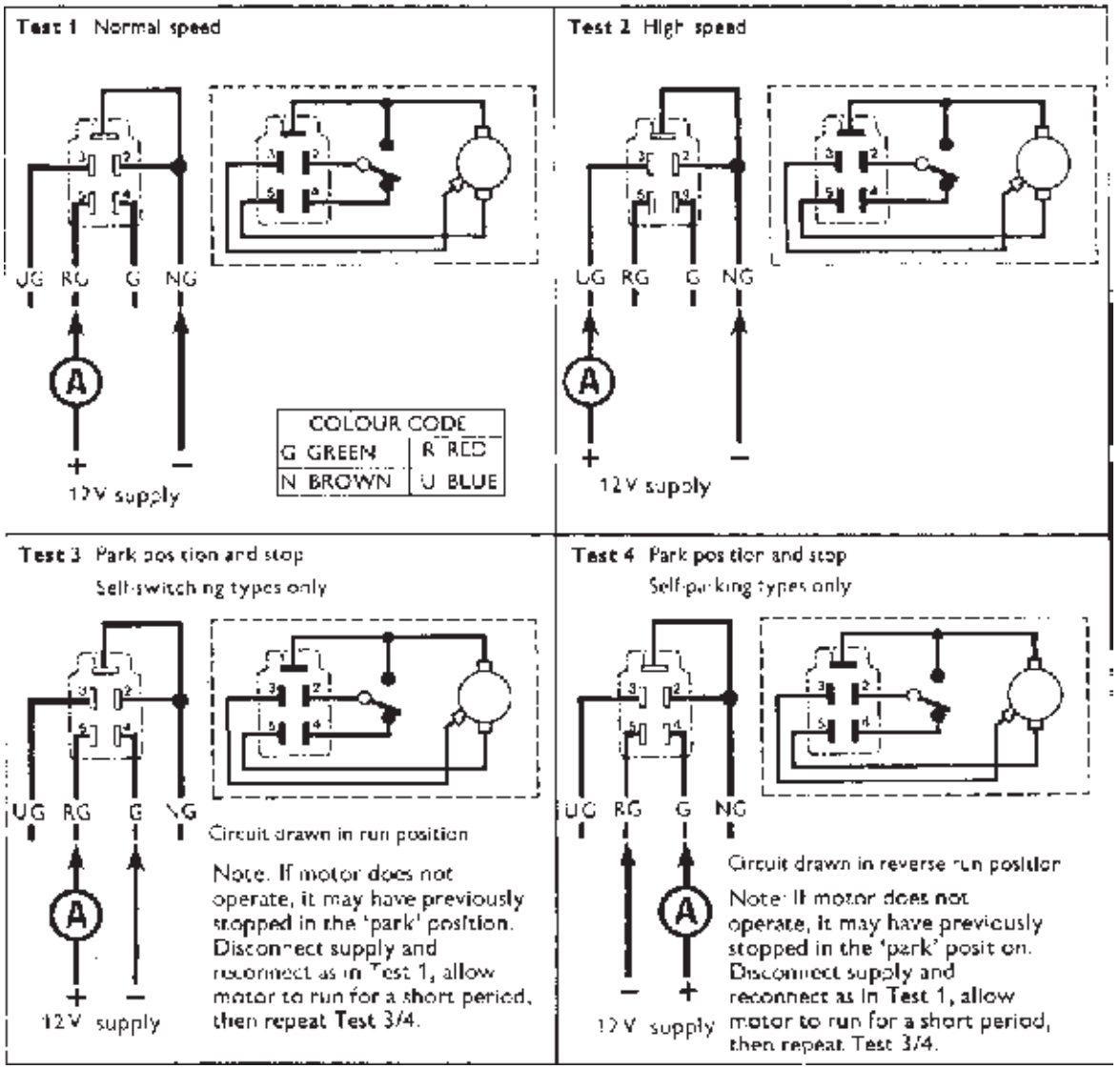


Figure 8.47 Early type wiper motor test procedure

8.8 In-car entertainment security and communications

8.8.1 In-car entertainment

Definition

MP3: An audio file format, based on MPEG (Moving Picture Expert Group) technology. It creates very small files suitable for streaming or downloading over the Internet.

Controls on most sets will include volume, treble, bass, balance and fade. A digital display will provide a visual output of operating condition (Figure 8.48). This is also linked into the vehicle lighting to prevent glare at night. Track selection and programming for one or several compact discs is possible. An MP3 input is now often provided.

Many in-car entertainment (ICE) systems are coded to deter theft. The code is activated if the main supply is disconnected and will not allow the set to work until the correct code has been re-entered. Some systems now include a plug in electronic 'key card', which makes the set worthless when removed.

Good ICE systems include at least six speakers, two larger speakers in the rear parcel shelf to produce good low-frequency reproduction, two front-door speakers for mid-range and two front-door tweeters for high-frequency notes (Figure 8.49). Speakers are a very important part of a sound system. No matter how good the receiver or CD player is, the sound quality will be reduced if inferior speakers are used. Equally, if the speakers are of a lower power output rating than the set, distortion will result at best and damage to the speakers at worst. Speakers fall generally into the following categories:

- tweeters high-frequency reproduction;
- mid-range frequency reproduction (treble);



Figure 8.48 ICE display and sub-woofer

- woofers low-frequency reproduction (bass);
- sub-woofers very low frequency reproduction.

The radio data system (RDS) has become a standard on many radio sets. It is an extra inaudible digital signal which is sent with FM broadcasts in a similar way to how teletext is sent with TV signals. RDS provides information so a receiver can appear to act intelligently. The possibilities available when RDS is used are as follows.

- The station name can be displayed in place of the frequency.
- There can be automatic tuning to the best available signal for the chosen radio station. For example, in the United Kingdom, a journey from the south of England to Scotland would mean the radio would have to be retuned up to 10 times. RDS will do this without the driver even knowing.
- Traff c information broadcasts can be identif ed and a setting made so that whatever you are listening to at the time can be interrupted.

The radio broadcast data system (RBDS) is an extension of RDS which has been in use in Europe since 1984. The system allows the broadcaster to transmit text information at the rate of approximately 1200 bits/s. The information is transmitted on a 57 kHz suppressed sub-carrier as part of the FM MPX signal.

RBDS was developed for the North American market by the National Radio Systems Committee (NRSC), a joint committee composed of the Electronic Industries Association (EIA) and the National Association of Broadcasters (NAB). The applications for the transmission of text to the vehicle are interesting and include

- song title and artist;
- traff c, accident and road hazard information;

Def nition

RDS: Radio data system.raff c information system on FM. RDS shows station name display and delivers traffc bulletins; it also locks onto the best possible frequency for a station in a particular part of the country.

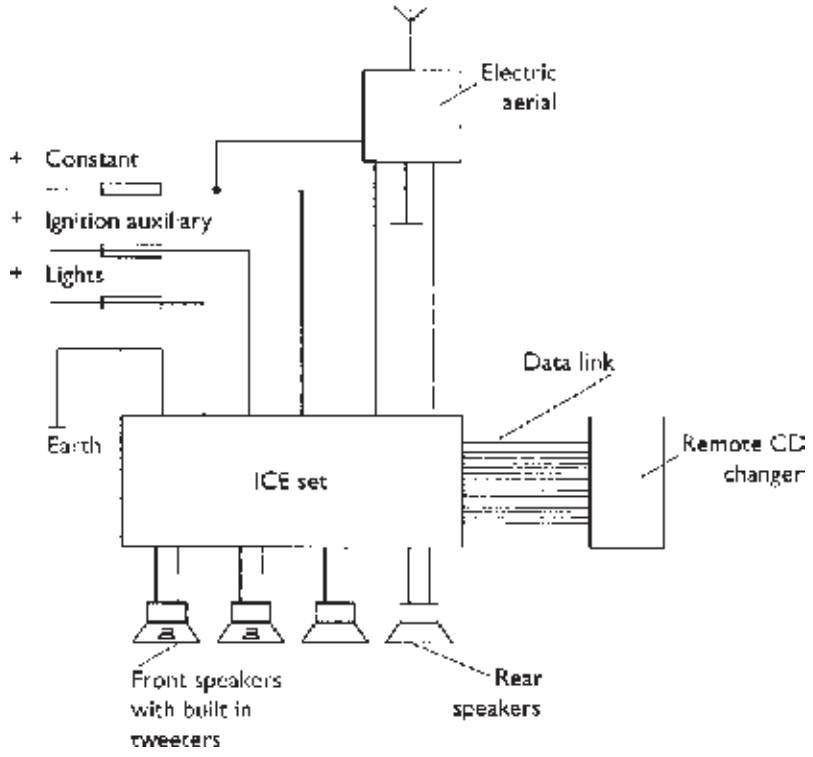


Figure 8.49 ICE circuit

- stock information;
- weather.

In emergency situations, the audio system can be enabled to interrupt the cassette, CD, or normal radio broadcast to alert the user.

8.8.2 Security systems

Car and alarm manufacturers are constantly f ghting to improve security. Building the alarm system as an integral part of the vehicle electronics has made signif cant improvements. Even so, retrof t systems can still be very effective. Three main types of intruder alarm are used:

- switch operated on all entry points;
- battery voltage sensed;
- volumetric sensing.

There are three main ways to disable the vehicle:

- ignition circuit cut off;
- starter circuit cut off;
- engine ECU code lock.

Most alarm systems are made for 12 V, negative earth vehicles. They have electronic sirens and give an audible signal when arming and disarming. They are all triggered when the car door opens and will automatically reset after a period of time, often one or two minutes. The alarms are triggered instantly when entry point is breached. Most systems are two pieces, with separate control unit and siren; most will have the control unit in the passenger compartment and the siren under the bonnet.

Most systems now come with remote 'keys' that use small button-type batteries and may have an LED that shows when the signal is being sent. They operate with one vehicle only. Intrusion sensors such as car movement and volumetric sensing can be adjusted for sensitivity.

When operating with f ashing lights, most systems draw approximately 5 A. Without f ashing lights (siren only), the current drawn is less than 1 A. The sirens produce a sound level of approximately 95 dB, when measured 2 m in front of the vehicle.

Key fact

Most factory-f tted alarms are combined with the central door locking system.

The system, as is usual, can be considered as a series of inputs and outputs. This is particularly useful for diagnosing faults. Most factory-f tted alarms are combined with the central door locking system. This allows the facility mentioned in a previous section known as lazy lock. Pressing the button on the remote unit, as well as setting the alarm, closes the windows and sunroof and locks the doors (Figure 8.50).

A security code in the engine ECU is a powerful deterrent. This can only be 'unlocked' to allow the engine to start when it receives a coded signal. Ford and other manufacturers use a special ignition key which is programmed with the required information. Even the correct 'cut' key will not start the engine.

Of course, nothing will stop the car being lifted onto a truck and driven away, but this technique will mean a new engine control ECU will be needed.

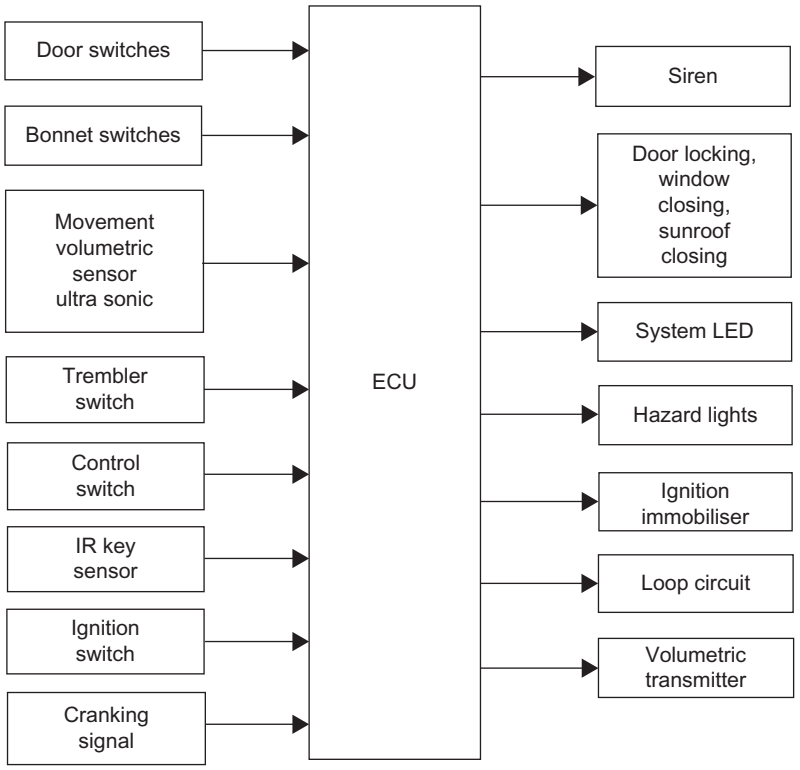


Figure 8.50 Block diagram of an alarm system

8.8.3 Mobile communications

If the success of the cellular industry is any indication of how much use we can make of the telephone, the future promises an even greater expansion. Cellular technology started to become useful in the 1980s and has continued to develop from then – very quickly.

Around this time, it was a specialised job to f t a car phone, but now this never happens. Many cars can link to standard mobile/cell now using Bluetooth. So, where does this leave communication systems relating to the vehicle? It is my opinion that 'in-vehicle' communication equipment for normal business and personal use will only ever be by the simple pocket-sized mobile cell phone and that there is no further market for the car telephone. Hands free conversions may still be important, but even these are built into many cars.

CB radios and short-range two-way systems such as those used by taxi f rms and service industries will still have a place for the time being. Even these will decline as the cellular network becomes cheaper and more convenient to use.

Key fact

The car phone is no more – standard mobiles and Bluetooth hands-free have taken over

8.9 Diagnostics – ICE, security and communication

8.9.1 Testing procedure

The process of checking an ICE system circuit is broadly as presented in Figure 8.51.

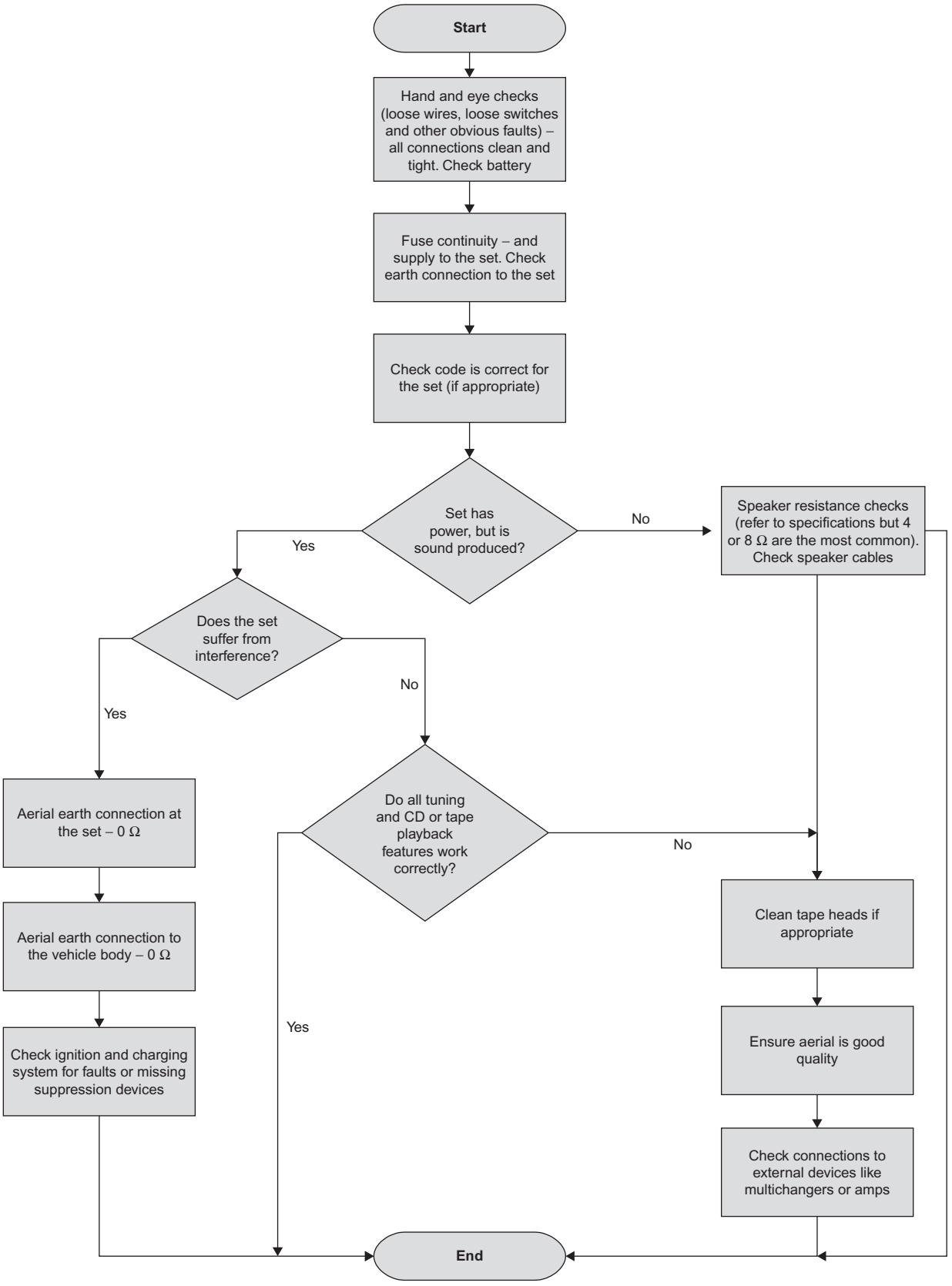


Figure 8.51 ICE system diagnosis chart

8.9.2 ICE, security and communication system fault diagnosis table

Symptom	Possible fault
Alarm does not operate	Fuse blown Not set correctly Remote key battery discharged Open circuit connection to alarm unit ECU fault Receiver/transmitter fault Volumetric transmitter/receiver fault
Alarm goes off for no apparent reason	Drain on battery Loose connection Vibration/trembler/movement detection circuit set too sensitive Self-discharge in the battery Window left open allowing wind or even a bird or insect to cause interior movement Somebody really is trying to steal the car Loose connection
Radio interference	Tracking HT components Static build up on isolated body panels High-resistance or open circuit aerial earth Suppression device open circuit
ICE system does not produce sound	Set not switched on! Loose or open circuit connections Trapped wires Connections to separate unit (amplifier, equaliser, etc.) incorrect Fuse blown
Unbalanced sound	Fade or balance controls not set correctly Speakers not wired correctly (front right, front left, rear right, rear left, etc.) Speaker open circuit or reduced output
Phasing	Speaker polarity incorrect. This should be marked, but if not, use a small battery to check all speakers are connected the same way. A small DC voltage will move the speaker cone in one direction.
Speaker rattle	Insecure speaker(s) Trim not secure Inadequate baffles
Crackling noises	If one speaker – then try substitution If one channel – swap connections at the set to isolate the fault If all channels but only the radio then check interference Radio set circuit fault
Vibration	Incorrect or loose mounting
Hum	Speaker cables routed next to power supply wires Set fault
Distortion	Incorrect power rating speakers

(*Continued*)

Symptom	Possible fault
Poor radio reception	Incorrect tuning 'Dark' spot/area. FM signals can be affected by tall buildings, etc. Aerial not fully extended Aerial earth loose or high resistance Tuner not trimmed to the aerial (older sets generally) Aerial sections not clean
Telephone reception poor	Low-battery power Poor reception area Interference from the vehicle Loose connections on hands free circuit

8.9.3 Interference suppression

Key fact

Most modern cars have to meet stringent EMC standards.

The process of interference suppression on a vehicle is to reduce the amount of unwanted noise produced from the speakers of an ICE system. This was at one time quite diff cult but now most modern cars have to meet EMC standards so no additional work is needed. There will always be older cars and exceptions, so read on!

To aid the discussion, it is necessary to f rst understand the different types of interference. Figure 8.52 shows two signals, one clean and the other suffering from interference. The amount of interference can be stated as a signal-to-noise ratio. This is the useful f eld strength compared to the interference f eld strength at the receiver.

There are two overall issues to be considered relating to suppression of interference on a vehicle. These are as follows:

- Short range – the effect of interference on the vehicle's radio system.
- Long range – the effect of the vehicle on external receivers such as domestic televisions. This is covered by legislation, making it illegal to cause disturbance to radios or televisions when using a vehicle.

Interference can propagate in one of four ways:

- line borne conducted through the wires;
- air borne radiated through the air to the aerial;
- capacitive coupling by an electric f eld;
- inductive coupling magnetic linking.

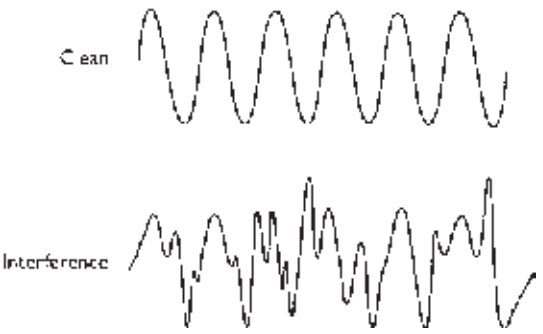


Figure 8.52 Radio signals

The sources of interference in the motor vehicle can be summarised quite simply as any circuit which is switched or interrupted suddenly. This includes the action of a switch and the commutation process in a motor, both of which produce rapidly increasing signals. The secret of suppression is to slow down this increase. Interference is produced from four main areas of the vehicle:

- ignition system;
- charging system;
- motors and switches;
- static discharges.

The ignition system of a vehicle is the largest source of interference, in particular the high-tension side. Voltages up to 50 kV are now common and the current for a fraction of a second when the plug f res can peak in excess of 100 A. The interference caused by the ignition system is mostly above 30 MHz and the energy can peak for fractions of a second in the order of 500 kW.

The charging system produces noise because of the sparking at the brushes. Electronic regulators produce few problems but regulators with vibrating contacts can cause trouble.

Any motor or switch including relays is likely to produce some interference. The most popular sources are the wiper motor and heater motor. The starter is not considered due to its short usage time.

Build-up of static electricity is due to friction between the vehicle and the air, and the tyres and the road. If the static on say the bonnet builds up more than on the wing, then a spark can be discharged. Using bonding straps to ensure all panels stay at the same potential easily prevents this. Because of the action of the tyres, a potential can build up between the wheel rims and the chassis unless suitable bonding straps are f tted. The arc to ground can be as much as 10 kV.

There are f ve main techniques for suppressing radio interference:

- resistors;
- bonding;
- screening;
- capacitors;
- inductors.

Resistance is used exclusively in the ignition HT circuit, up to a maximum of approximately 20 kΩ per lead. This has the effect of limiting the peak current, which in turn limits the peak electromagnetic radiation. Providing excessive resistance is not used, the spark quality is not affected. These resistors effectively damp down the interference waves.

Bonding has been mentioned earlier. It is simply to ensure that all parts of the vehicle are at the same electrical potential to prevent sparking due to the build-up of static.

Screening is generally only used for specialist applications such as emergency services and the military. It involves completely enclosing the ignition system and other major sources of noise in a conductive screen, which is connected to the vehicle's chassis earth. This prevents interference waves escaping, it is a very effective technique but expensive. Often a limited amount of screening can be used to good effect, for example metal covers on the plugs.

Capacitors and inductors are used to act as f lters. This is achieved by using the changing value of 'resistance' to alternating signals as the frequency increases. The correct term for this resistance is either capacitive or inductive reactance.

Key fact

Capacitors and inductors can be used as electrical lters.

By choosing suitable values of capacitor in parallel and/or inductor in series, it is possible to f lter out unwanted signals of certain frequencies.

Several types of aerial are in use; the most popular still being the rod aerial which is often telescopic. The advantage of a rod aerial is that it extends beyond the interference f eld of the vehicle. For reception in the AM bands, the aerial represents a capacitance of 80 pF with a shunt resistance of approximately 1 MΩ. The set will often incorporate a trimmer to ensure that the aerial is matched to the set. Contact resistance between all parts of the aerial should be less than 20 Ω. This is particularly important for the earth connection.

When receiving in the FM range, the length of the aerial is very important. The ideal length of a rod aerial for FM reception is one quarter of the wavelength. In the middle of the FM band (94 MHz) this is approximately 80 cm. Because of the magnetic and electrical f eld of the vehicle and the effect of the coaxial cable, the most practical length is approximately 1 m. Some smaller aerials are available but while these may be more practical the signal strength is reduced. Aerials embedded into the vehicle windows or using the heated rear window element are good from the damage prevention aspect and for insensitivity to moisture, but produce a weaker signal often requiring an aerial amplif er to be included. Note that this will also amplify interference. Some top range vehicles use a rod aerial and a screen aerial, the set being able to detect and use the strongest signal. This reduces the effect of ref ected signals and causes less f utter.

Consideration must be given to the position of an external aerial. This has to be a compromise, taking into account the following factors:

- rod length – 1 m, if possible;
- coaxial cable length – longer cable reduces the signal strength;
- position – as far away as reasonably possible from the ignition system;
- potential for vandalism – out of easy reach;
- aesthetic appearance – whether it f ts with the style of the vehicle;
- angle of f tting – vertical is best for AM and horizontal for FM.

Most quality sets also include a system known as interference absorption. This is a circuit built in to the set consisting of high-quality f lters and is not adjustable.

8.10 Body electrical systems

8.10.1 Electric seat adjustment

Adjustment of the seat is achieved by using a number of motors to allow positioning of different parts of the seat. A typical motor reverse circuit is shown in Figure 8.53.

When the switch is moved, one of the relays will operate and this changes the polarity of the supply to one side of the motor. Movement is often possible in the following ways:

- front to rear;
- cushion height rear;
- cushion height front;
- backrest tilt;
- headrest height;
- lumbar support.

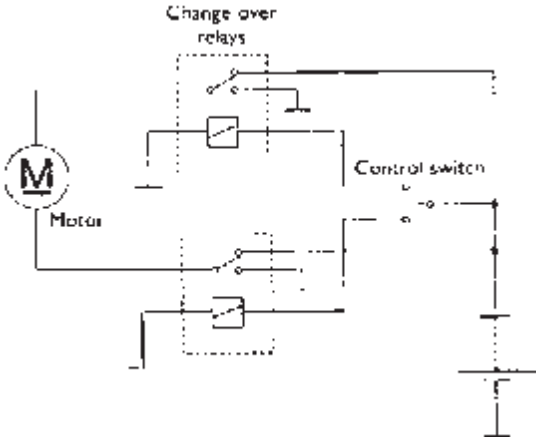


Figure 8.53 Motor reverse circuit using a centre-off changeover switch and two changeover relays

When seat position is set, some vehicles have position memories to allow automatic repositioning, if the seat has been moved. This is often combined with electric mirror adjustment. Figure 8.54 shows how the circuit is constructed to allow position memory. As the seat is moved, a variable resistor, mechanically linked to the motor, is also moved. The resistance value provides feedback to an ECU.

This can be 'remembered' in a number of ways; the best technique is to supply the resistor with a f xed voltage such that the output relative to the seat position is proportional to position. This voltage can then be 'analogue to digital' converted, which produces a simple 'number' to store in a digital memory. When the driver presses a memory recall switch, the motor relays are activated by the ECU until the number in memory and the number fed back from the seat are equal. This facility is often isolated when the engine is running to prevent the seat moving into a dangerous position as the car is being driven. Position of the seats can still be adjusted by operating the switches as normal.

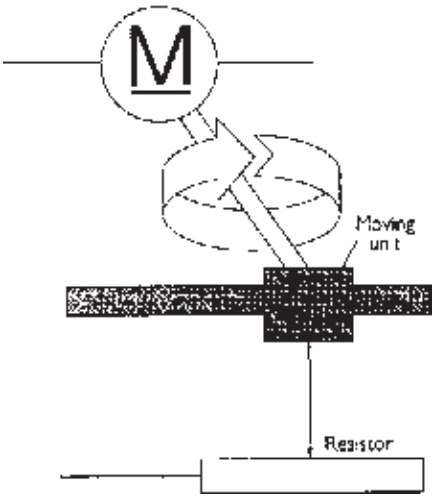


Figure 8.54 One method for position memory

8.10.2 Electric mirrors

Many vehicles have electrical adjustment of mirrors, particularly on the passenger side. The system used is much the same as has been discussed above in relation to seat movement. Two small motors are used to move the mirror vertically or horizontally. Many mirrors also contain a small heating element on the rear of the glass. This is operated for a few minutes when the ignition is f rst switched on and can also be linked to the heated rear window circuit. The following f gure shows an electrically operated mirror circuit, which includes feedback resistors for positional memory (Figure 8.55).

8.10.3 Electric sunroof operation

The operation of an electric sunroof is similar to the motor reverse circuit discussed earlier in this chapter. However, further components and circuitry are needed to allow the roof to slide, tilt and stop in the closed position. The extra components used are a micro switch and a latching relay. A latching relay works in much the same way as a normal relay except that it locks into position each time it is energised. The mechanism used to achieve this is much like that used in ball point pens that use a button on top (Figure 8.56).

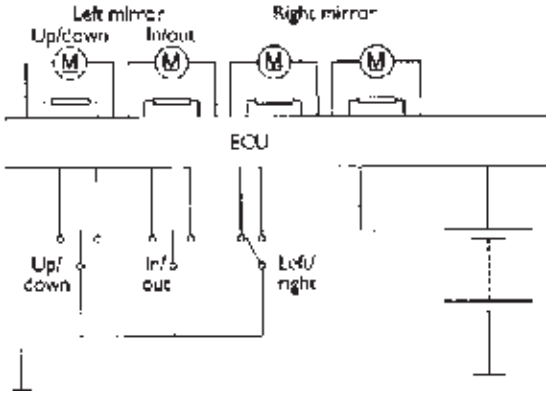


Figure 8.55 Mirror adjustment circuit

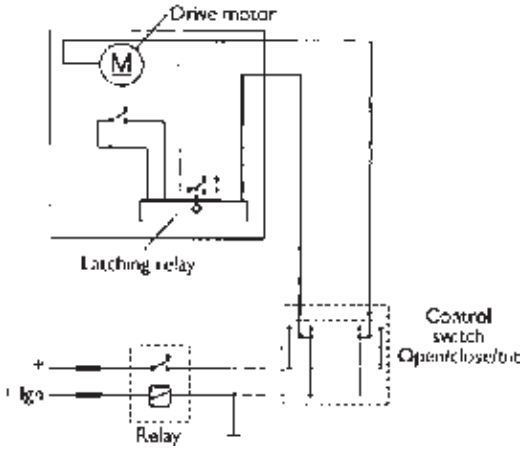


Figure 8.56 Sunroof circuit example

The micro switch is mechanically positioned such as to operate when the roof is in its closed position. A rocker switch allows the driver to adjust the roof. The switch provides the supply to the motor to run it in the chosen direction. The roof will be caused to open or tilt. When the switch is operated to close the roof, the motor is run in the appropriate direction until the micro switch closes when the roof is in its closed position. This causes the latching relay to change over, which stops the motor. The control switch has now to be released. If the switch is pressed again, the latching relay will once more change over and the motor will be allowed to run.

8.10.4 Door locking circuit

When the key is turned in the driver's door lock, all the other doors on the vehicle should also lock. Motors or solenoids in each door achieve this. If the system can only be operated from the driver's door key, then an actuator is not required in this door. If the system can be operated from either front door or by remote control, then all the doors need an actuator. Vehicles with sophisticated alarm systems often lock all the doors as the alarm is set.

The main control unit in the following f gure contains two changeover relays. These are actuated by either the door lock switch or, if f tted, the remote infrared key. The motors for each door lock are simply wired in parallel and all operate at the same time (Figure 8.57).

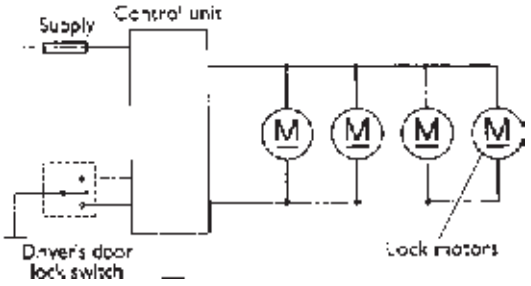


Figure 8.57 Door lock circuit

Most door actuators are now small motors which, via suitable gear reduction, operate a linear rod in either direction to lock or unlock the doors. A simple motor reverse circuit is used to achieve the required action.

Remote central door locking is controlled by a small hand-held transmitter and an infrared or RF sensor receiver unit as well as a decoder in the main control unit. This layout will vary slightly between different manufacturers. When the infrared key is operated by pressing a small switch, a complex code is transmitted. The number of codes used is well in excess of 50 000. The infrared sensor picks up this code and sends it in an electrical form to the main control unit. If the received code is correct, the relays are triggered and the door locks are either locked or unlocked. If an incorrect code is received on three consecutive occasions when attempting to unlock the doors, then the infrared system will switch itself off until the door is opened by the key. This will also reset the system and allow the correct code to again operate the locks. This technique prevents a scanning-type transmitter unit from being used to open the doors.

8.10.5 Electric window operation

The basic form of electric window operation is similar to many of the systems discussed so far in this chapter, that is a motor-reversing system either by relays or directly by a switch. More sophisticated systems are now becoming more popular for reasons of safety as well as improved comfort. The following features are now available from many manufacturers:

- one-shot up or down;
- inch up or down;
- lazy lock;
- back-off.

When a window is operated in one-shot or one-touch mode, the window is driven in the chosen direction until either the switch position is reversed, the motor stalls or the ECU receives a signal from the door lock circuit. The problem with one-shot operation is that if a child, for example, gets trapped in the window, there is a serious risk of injury. To prevent this, the back-off feature is used. An extra commutator is f tted to the motor armature and produces a signal via two brushes, proportional to the motor speed. If the rate of change of speed of the motor is detected as being below a certain threshold when closing, then the ECU will reverse the motor until the window is fully open. By counting the number of pulses received, the ECU can also determine the window position.

This is important, as the window must not reverse when it stalls in the closed position. In order for the ECU to know the window position, it must be initialised.

Key fact

To prevent children (or others) becoming trapped in an auto-close window, a back-off feature is used.

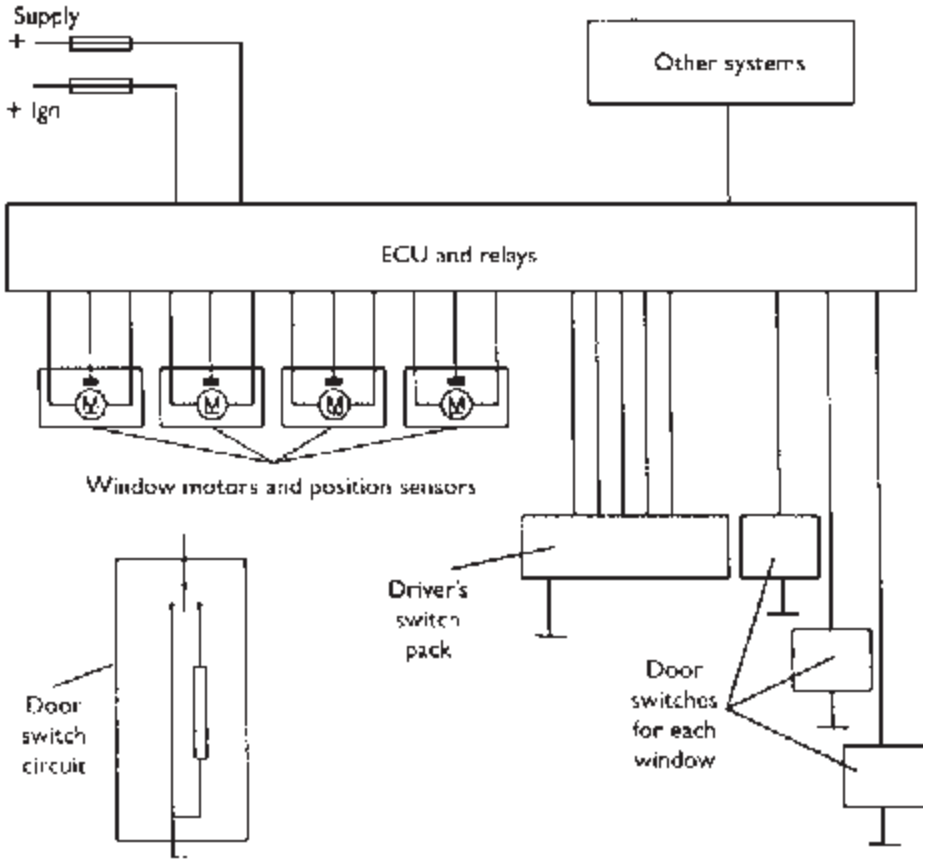


Figure 8.58 Electric window circuit

This is often done simply by operating the motor to drive the window first fully open and then fully closed. If this is not done, then the one-shot close will not operate. On some systems, Hall effect sensors are used to detect motor speed. Other systems sense the current being drawn by the motor and use this as an indication of speed.

Lazy lock feature allows the car to be fully secured by one operation of a remote key. This is done by the link between the door lock ECU and the window and sunroof ECUs. A signal is supplied which causes all the windows to close in turn and then the sunroof, and finally locks the doors. The alarm will also be set, if required. The windows close in turn to prevent the excessive current demand which would occur if they all tried to operate at the same time.

A circuit for electric windows is shown in Figure 8.58. Note the connections to other systems such as door locking and the rear window isolation switch. This is commonly fitted to allow the driver to prevent rear window operation for child safety, for example.

8.11 Diagnostics – body electrical

8.11.1 Testing procedure

The following procedure is very generic but with a little adaptation can be applied to any electrical system. Refer to manufacturer's recommendations if in any doubt. The process of checking any system circuit is broadly as presented in Figure 8.59.

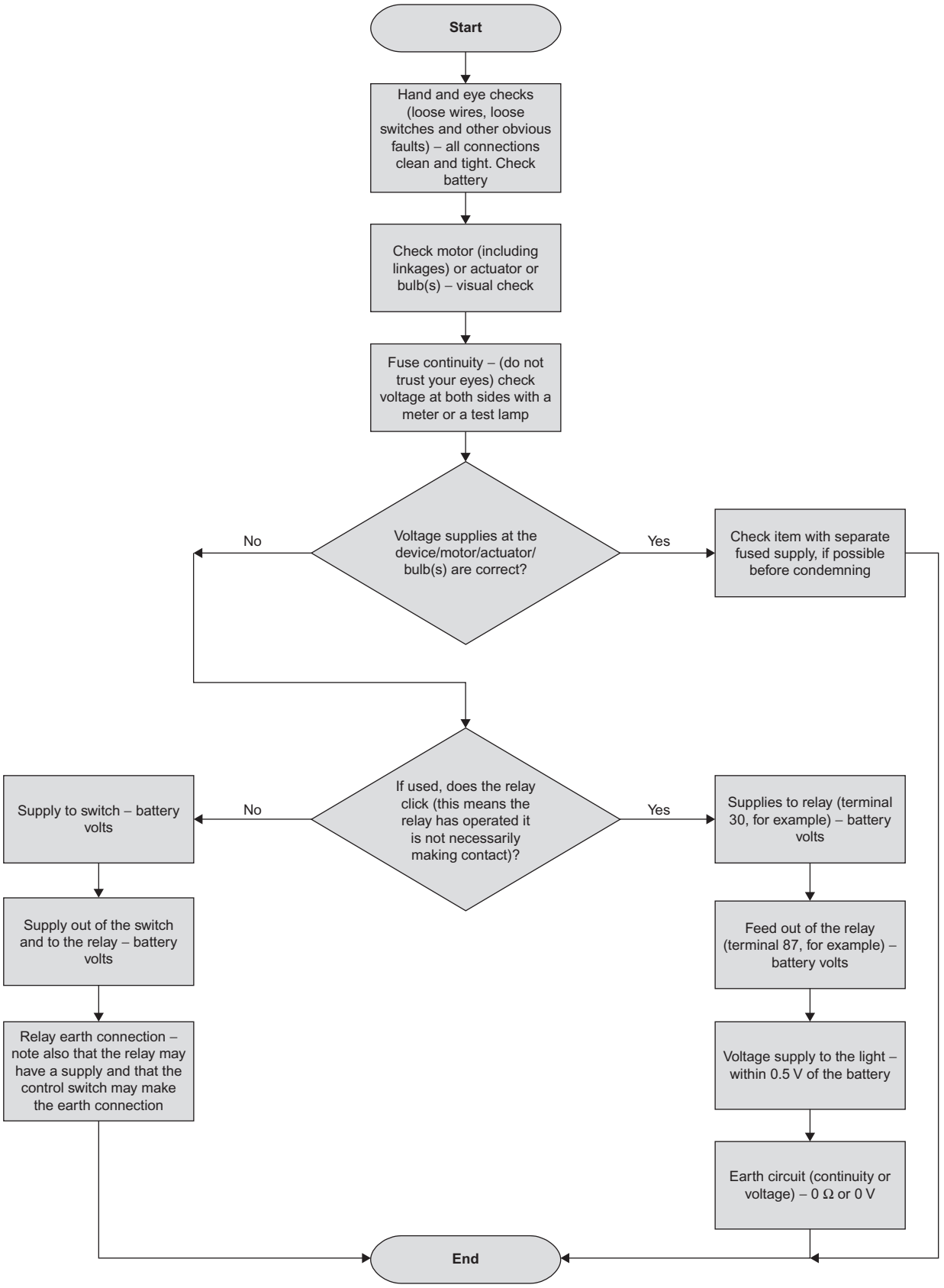


Figure 8.59 Auxiliary and body systems diagnosis chart

8.11.2 Body electrical systems fault diagnosis table

Symptom	Possible fault
Electric units not operating	If ALL units not operating Open circuit in main supply Main fuse blown
Unit = window, door lock, mirror, etc.	Relay coil or contacts open circuit or high resistance If ONE unit is not operating Fuse blown Control switch open circuit Motor seized or open circuit Back-off safety circuit signal incorrect (windows)

8.11.3 Circuit systematic testing

The circuit shown in Figure 8.60 is for a power hood (meaning roof in this case) on a vehicle. The following faultf nding guide is an example of how to approach a problem with a system such as this in a logical manner.

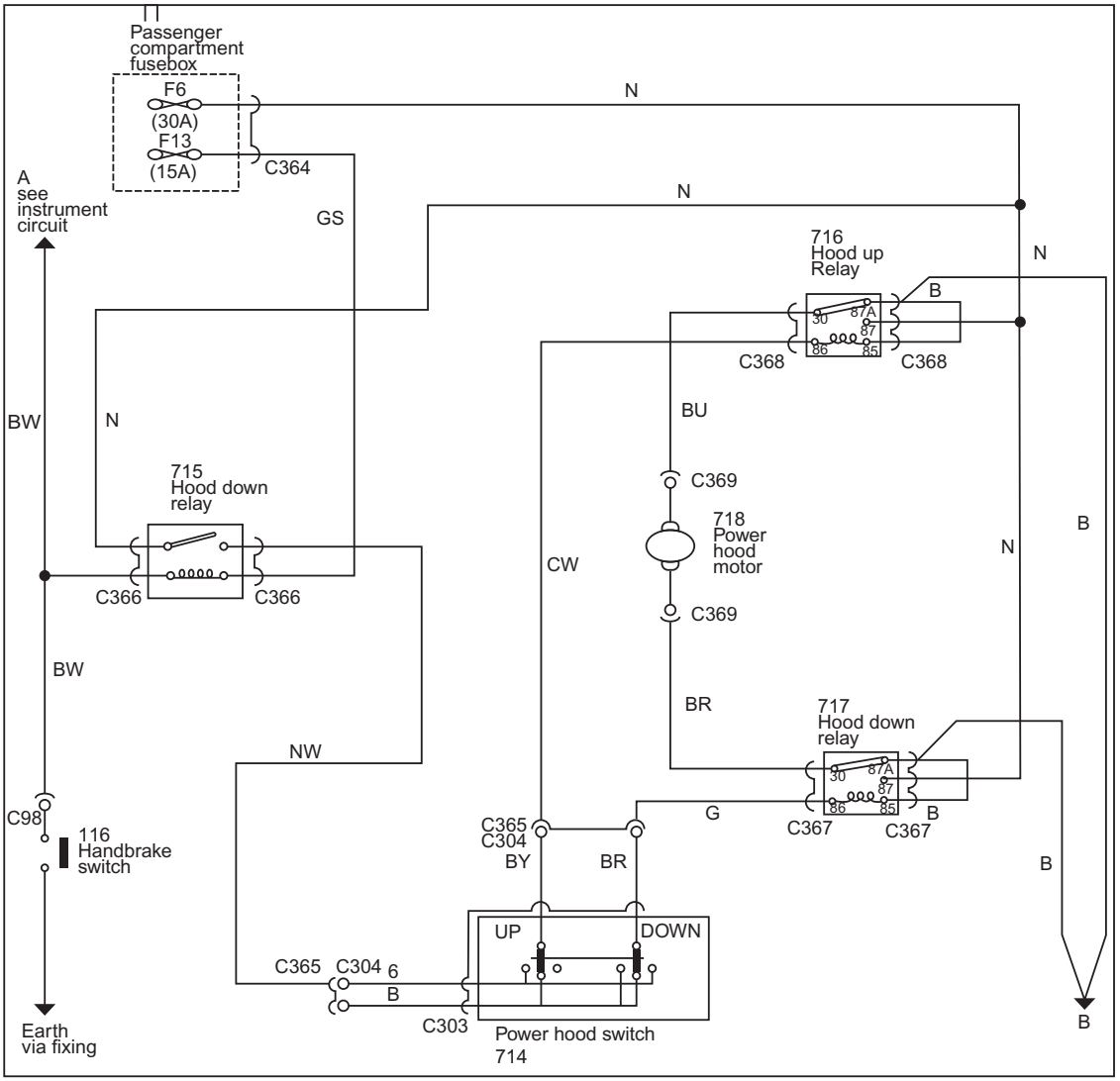


Figure 8.60 Power hood (roof) circuit

If the power hood will not operate with the ignition switch at the correct position and the handbrake applied, proceed as follows:

1 Check fuses 6 and 13.
2 Check 12 V supply on N wire from fuse 6.
3 Check for 12 V on GS wire at power hood relay.
4 Check continuity from power hood relay to earth on BW wire.
5 Check power hood relay.
6 Check for 12 V on NW wire at hood switch. Check for 12 V on N wire at hood up and down relays.
7 Check continuity from hood up and down relays to earth on B wire.
8 Check switch operation.
9 Check pump motor operation.

If the power hood will operate in one direction only, proceed as follows:

1 Check for 12 V on N wire at hood up or down relay as appropriate.
2 Check continuity from hood up or down relay to earth on B wire.
3 Check relay.

8.12 Instrumentation

8.12.1 Gauges

Thermal gauges, which are ideal for fuel and engine temperature indication, have been in use for many years. This will continue because of their simple design and inherent 'thermal' damping. The gauge works by utilising the heating effect of electricity and the widely adopted benef t of the bimetal strip. As a current f ows through a simple heating coil wound on a bimetal strip, heat causes the strip to bend. The bimetal strip is connected to a pointer on a suitable scale. The amount of bend is proportional to the heat, which in turn is proportional to the current f owing. Provided the sensor can vary its resistance in proportion to the measurement (e.g. fuel level), the gauge will indicate a suitable representation as long as it has been calibrated for the particular task. Figure 8.61 shows a representation of a typical thermal gauge circuit.

Key fact

With a bimetal strip, the amount of bend is proportional to the heat, which in turn is proportional to the current fowing.

Thermal-type gauges are used with a variable resistor and f oat in a fuel tank or with a thermistor in the engine water jacket. The resistance of the fuel tank sender can be made non-linear to counteract any non-linear response of the gauge. The sender resistance is at a maximum when the tank is empty.

A constant voltage supply is required to prevent changes in the vehicle system voltage affecting the reading. This is because if system voltage increased, the

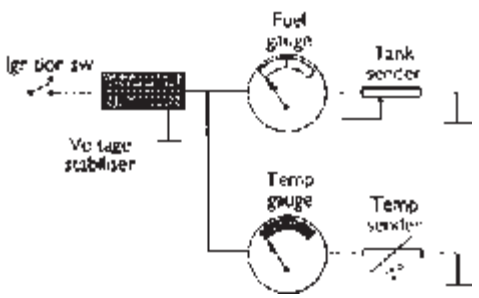


Figure 8.61 Simplif ed thermal gauge circuit

current f owing would increase and hence the gauges would read higher. Most voltage stabilisers are simple zener diode circuits.

Air-cored gauges work on the same principle as a compass needle lining up with a magnetic f eld. The needle of the display is attached to a very small permanent magnet. Three coils of wire are used and each produces a magnetic f eld. The magnet will line up with the resultant of the three f elds. The current f owing and the number of turns (ampere-turns) determine the strength of the magnetic f ux produced by each coil. As the number of turns remains constant, the current is the key factor. Figure 8.62 shows the principle of the air-cored gauge together with the circuit for use as a temperature indicator. The ballast resistor on the left is used to limit maximum current and the calibration resistor is used for calibration. The thermistor is the temperature sender. As the thermistor resistance is increased, the current in all three coils will change. Current through C will be increased but the current in coils A and B will decrease.

Key fact

Air-cored gauges work on the same principle as a compass needle lining up with a magneticefd.

The air-cored gauge has a number of advantages. It has almost instant response, and as the needle is held in a magnetic f eld it will not move as the vehicle changes position. The gauge can be arranged to continue to register the last position even when switched off or, if a small 'pull off' magnet is used, it will return to its zero position. As a system voltage change would affect the current f owing in all three coils, variations are cancelled out negating the need for voltage stabilisation. Note that the operation is similar to the moving iron gauge.

8.12.2 Digital instrumentation

The block diagram shown in Figure 8.63 is the representation of a digital instrumentation system. All signal conditioning and logic functions are carried out in the ECU. This will often form part of the dashboard assembly. Standard sensors provide information to the ECU, which in turn will drive suitable displays. The ECU contains a ROM (read only memory) section, which allows it to be programmed to a specif c vehicle. The gauges used are as described in the

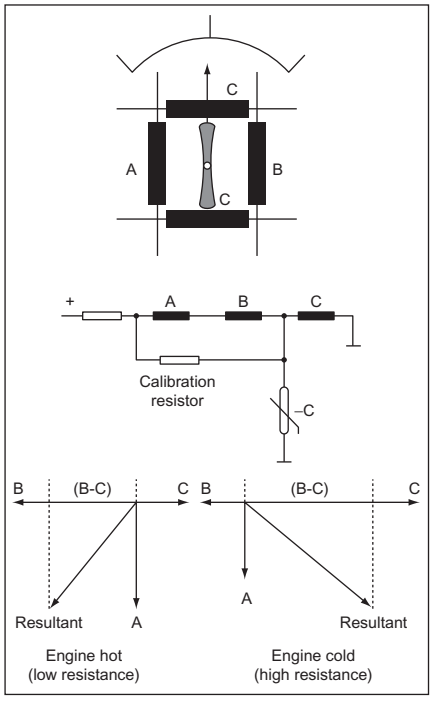


Figure 8.62 Principle of an aircored gauge and the circuit used for engine temperature

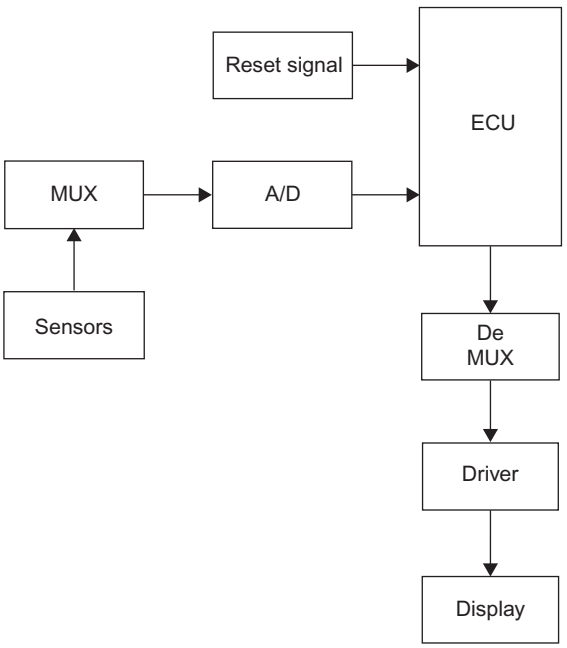


Figure 8.63 Digital instrumentation block diagram

above sections. Some of the extra functions available with this system are described brief y as follows:

- Low fuel warning light: Can be made to illuminate at a particular resistance reading from the fuel tank sender unit.
- High engine temperature warning light: Can be made to operate at a set resistance of the thermistor.
- Steady reading of the temperature gauge: To prevent the gauge f uctuating as the cooling system thermostat operates, the gauge can be made to read only at say f ve set f gures. For example, if the input resistance varies from 240 to 200 Ω as the thermostat operates, the ECU will output just one reading corresponding to 'normal' on the gauge. If the resistance is much higher or lower, the gauge will read to one of the f ve higher or lower positions. This gives a low resolution but high readability for the driver.
- Oil pressure or other warning lights can be made to f ash: This is more likely to catch the driver's attention.
- Service or inspection interval warning lights can be used: The warning lights are operated broadly as a function of time but, for example, the service interval is reduced if the engine experiences high speeds and/or high temperatures. Oil condition sensors are also used to help determine service intervals.
- Alternator warning light: Works as normal, but the same or an extra light can be made to operate if the output is reduced or if the drive belt slips. This is achieved by a wire from one phase of the alternator providing a pulsed signal, which is compared to a pulsed signal from the ignition. If the ratio of the pulses changed, this would indicate a slipping belt.

8.12.3 Vehicle condition monitoring

Vehicle condition monitoring (VCM) is a sort of enhancement to the normal instrumentation system. For example, a warning light added to a gauge as shown in Figure 8.64.



Figure 8.64 Low fuel warning

A system may include driver information relating to the following list:

- high engine temperature;
- low fuel;
- low brake f uid;
- worn brake pads;
- low coolant level;
- low oil level;
- low screen washer f uid;
- low outside temperature;
- bulb failure;
- doors, bonnet, hood or boot open warning.

A circuit is shown in Figure 8.65 that can be used to operate bulb failure warning lights for whatever particular circuit it is monitoring. The simple principle is that the reed relay is only operated when the bulb being monitored is drawing current. The f uid and temperature level monitoring systems work in a similar way to the systems described earlier, but in some cases the level of a f uid is by a f oat and switch.

Oil level can be monitored by measuring the resistance of a heated wire on the end of the dip stick. A small current is passed through the wire to heat it. How much of the wire is covered by oil will determine its temperature and therefore resistance.

Key fact

Many of the circuits monitored use a dual-resistance system so that the circuit itself is also checked.

Many of the circuits monitored use a dual-resistance system so that the circuit itself is also checked (Figure 8.66). In effect, it will produce one of three possible outputs: high-resistance, low-resistance or an out-of-range reading. The high- or

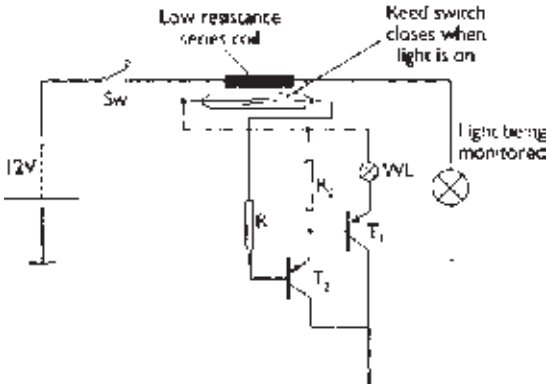


Figure 8.65 Bulb failure warning circuit

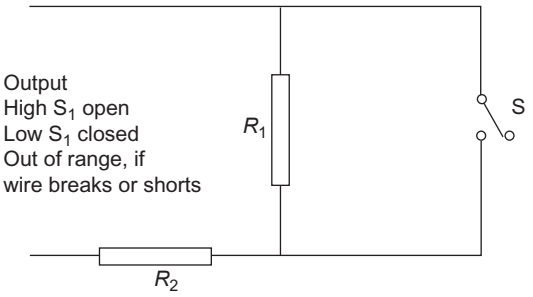


Figure 8.66 Dual-resistance self-testing system

low-resistance readings are used to indicate say correct f uid level and low f uid level. A f gure outside these limits would indicate a circuit fault of either a short or open circuit connection.

The display on earlier cars was often just a collection of LEDs or a backlit liquid crystal display (LCD). These were even arranged into suitable patterns and shapes such as to represent the circuit or system being monitored.

However, the current trend is to just present information as requested by the driver or to present only what is important at any particular time. Low outside temperature or ice warning is often a large snowf ake, or a tyre pressure issue is notif ed using a symbol shown in Figure 8.67.

8.12.4 Trip computer

The trip computer used on many top range vehicles is arguably an expensive novelty, but is popular nonetheless. The functions available on most systems are

- time and date;
- elapsed time or a stop watch;
- estimated time of arrival;
- average fuel consumption;
- range on remaining fuel;
- trip distance.

The above details can usually be displayed in imperial, US or metric units as required. Note that several systems use the same inputs and that several systems 'communicate' with each other. This makes the overall wiring very bulky – if not complicated.

8.12.5 Displays

If the junction of a diode is manufactured in a certain way, light will be emitted from the junction when a current is made to pass in the forward biased direction. This is an LED and will produce red, yellow or green light with slight changes in the manufacturing process. LEDs are used extensively as indicators on electronic equipment and in digital displays. They last for a very long time (50 000 hours) and draw only a small current (Figure 8.68).

LED displays are tending to be replaced with the liquid crystal type for automobile use, which can be backlit to make it easier to read in the daylight.



Figure 8.67 Low tyre pressure warning symbol



Figure 8.68 Instrument display combining analogue and digital displays

Key fact

LED displays are tending to be replaced with the liquid crystal type for automobile use, which can be backlit to make it easier to read in the daylight.

However, LEDs are still popular for many applications. The actual display will normally consist of a number of LEDs arranged into a suitable pattern for the required output. This can range from the standard seven-segment display to show numbers, to a custom-designed speedometer display.

Liquid crystals are substances that do not melt directly from a solid to the liquid phase, but first pass through a para-crystalline stage in which the molecules are partially ordered. In this stage, a liquid crystal is a cloudy or translucent fluid but still has some of the optical properties of a solid crystal.

Mechanical stress, electric and magnetic fields, pressure and temperature can alter the molecular structure of liquid crystals. A liquid crystal also scatters light that shines on it. Because of these properties, liquid crystals are used to display letters and numbers on calculators, digital watches and automobile instrument displays. LCDs are also used for portable computer screens and even television screens. The LCD has many more areas of potential use and developments are ongoing. In particular, this type of display is now good enough to reproduce pictures and text on computer and TV screens.

8.13 Diagnostics – instruments

8.13.1 Testing procedure

The process of checking a thermal gauge fuel or temperature instrument system is broadly as presented in Figure 8.69.

8.13.2 Instrumentation fault diagnosis table

Symptom	Possible fault
Fuel and temperature gauges both read high or low	Voltage stabiliser
Gauges read full/hot or empty/cold all the time	Short/open circuit sensors Short or open circuit wiring
Instruments do not work	Loose or broken wiring/connections/fuse Inoperative instrument voltage stabiliser Sender units (sensor) faulty Gauge unit fault (not very common)

8.13.3 Black box technique for instrumentation

Instrumentation systems, like most others, now revolve around an ECU. The ECU is considered to be a 'black box'; in other words, we know what it should do, but how it does it is irrelevant. Figure 8.70 shows an instrumentation system where the instrument pack could be considered as a black box. Normal faultfinding or testing techniques can now be applied to the sensors and supply circuits.

Safety first

Warning: The circuit supply must always be off when carrying out ohmmeter tests.

Remember also the 'sensor to ECU method' of testing described in Chapter 2. A resistance test carried out on a component such as the tank unit (lower right) would give a direct measure of its resistance. A second reading at the instrument pack between the GB and BP wires, if the same as the first, would confirm that the circuit is in good order.

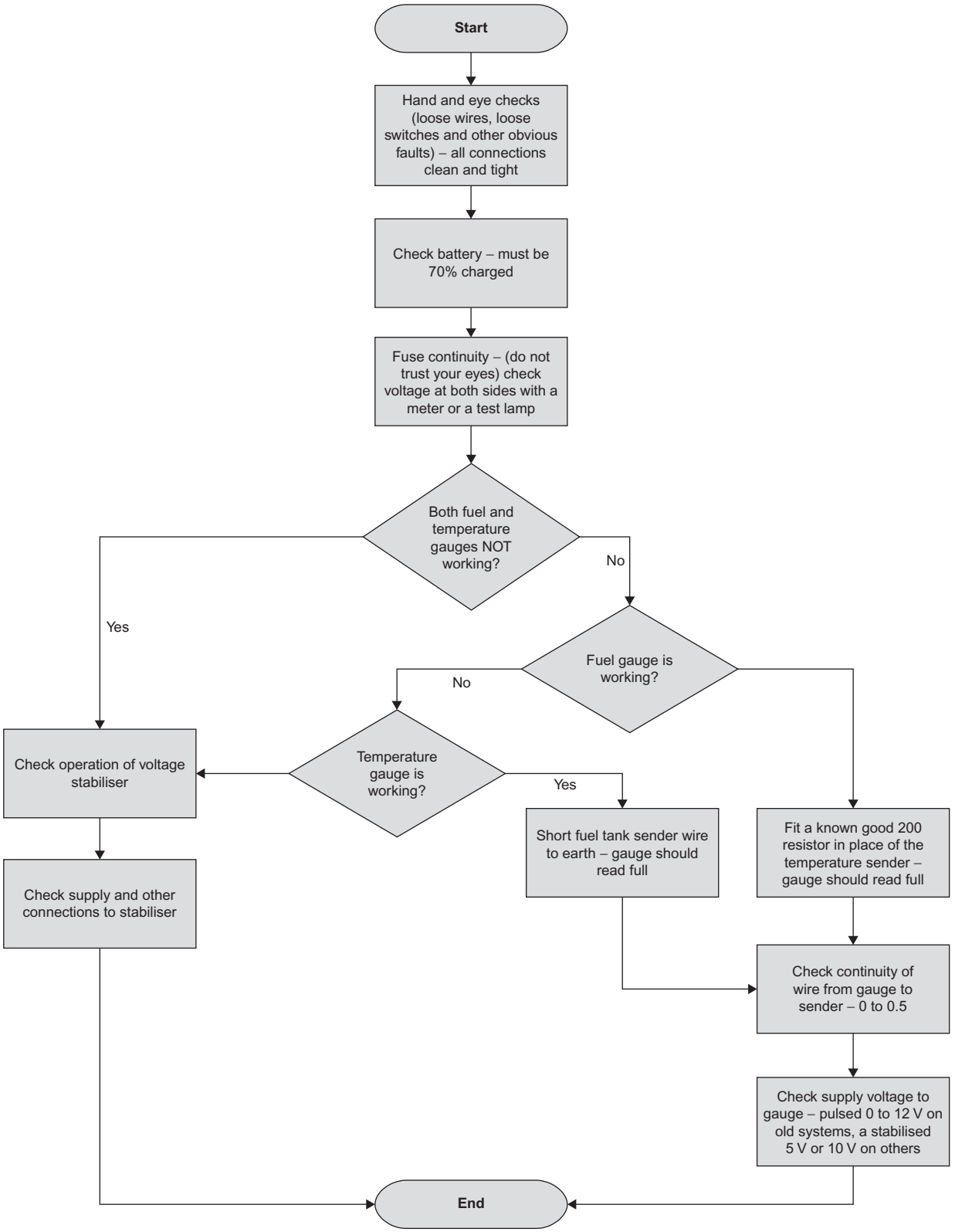


Figure 8.69 Instrumentation diagnosis chart

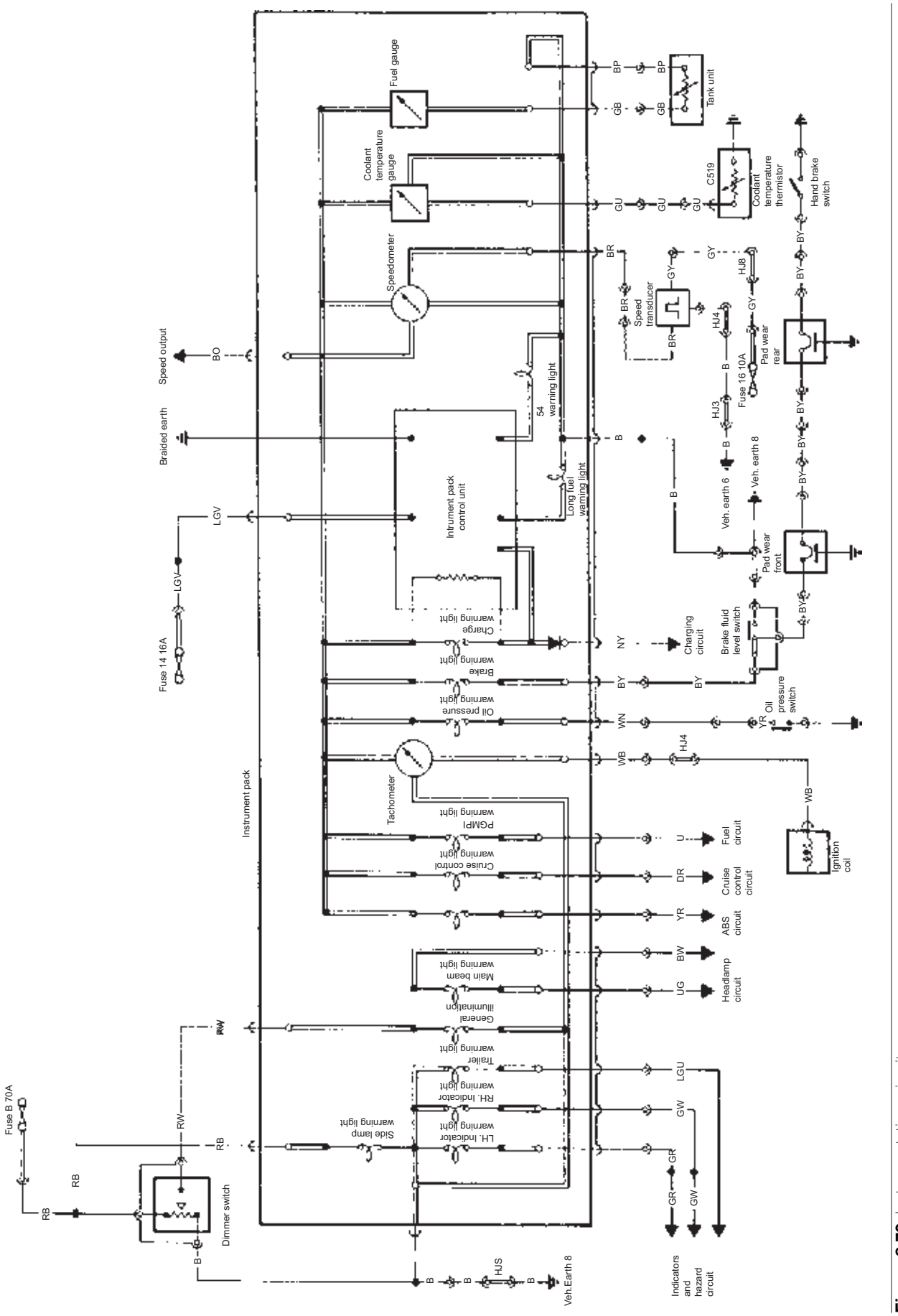


Figure 8.70 Instrumentation circuit

8.14 Heating, ventilation and air conditioning

8.14.1 Ventilation and heating

To allow fresh air from outside the vehicle to be circulated inside the cabin, a pressure difference must be created. This is achieved by using a plenum chamber. A plenum chamber by def nition holds a gas (in this case air) at a pressure higher than the ambient pressure. The plenum chamber on a vehicle is usually situated just below the windscreen, behind the bonnet. When the vehicle is moving, the airf ow over the vehicle will cause a higher pressure in this area. Suitable f aps and drains are utilised to prevent water entering the car through this opening.

By means of distribution trunking, control f aps and suitable 'nozzles', the air can be directed as required. This system is enhanced with the addition of a variable speed blower motor. When extra air is forced into a vehicle cabin, the interior pressure would increase if no outlet was available. Most passenger cars have the outlet grilles on each side of the vehicle above or near the rear quarter panels or doors.

Def nition

Plenum chamber: A pressurised housing containing a gas ouid (typically air) at positive pressure (pressure higher than surroundings). One function of a plenum can be to equalise pressure for more even distribution, because of irregular supply or demand.

8.14.2 Heating system – water-cooled engine

Heat from the engine is utilised to increase the temperature of the car interior. This is achieved by use of a heat exchanger, called the heater matrix. Because of the action of the thermostat in the engine cooling system, the water temperature remains broadly constant. This allows for the air being passed over the heater matrix to be heated by a set amount depending on the outside air temperature and the rate of airf ow. A source of hot air is therefore available for heating the vehicle interior. However, some form of control is required over how much heat (if any) is required. The method used on most modern vehicles is the blending technique. This is simply a control f ap, which determines how much of the air being passed into the vehicle is directed over the heater matrix. The main drawback of this system is the change in airf ow with vehicle speed. Some systems use a valve to control the hot coolant f owing to the heater matrix (Figure 8.71).

Def nition

HVAC: Heating, ventilation and air conditioning.

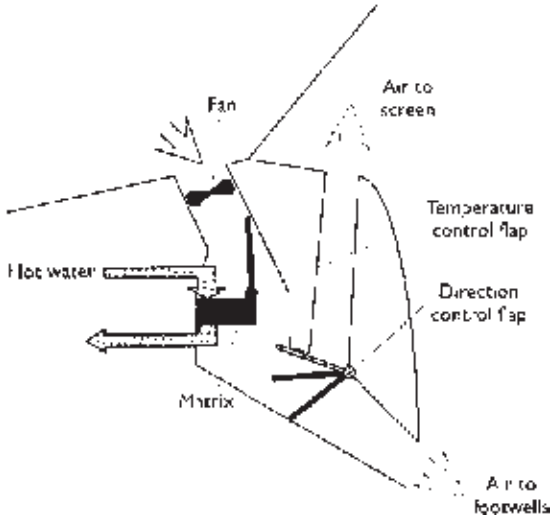


Figure 8.71 Heating and ventilation system

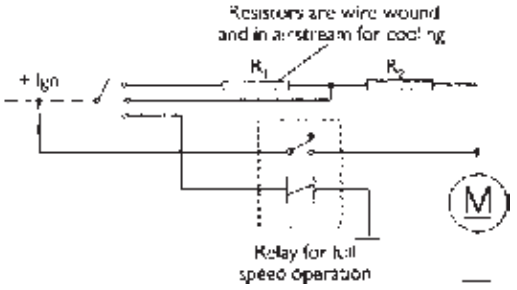


Figure 8.72 Three-speed motor control circuit

By a suitable arrangement of flaps, it is possible to direct air of the chosen temperature to selected areas of the vehicle interior. In general, basic systems allow the warm air to be adjusted between the inside of the windscreen and the driver and passenger footwells. Most vehicles also have small vents directing warm air at the driver's and front passenger's side windows. Fresh cool air outlets with directional nozzles are also fitted.

One final facility, which is available on many vehicles, is the choice between fresh or recirculated air. The main reason for this is to decrease the time it takes to demist or defrost the vehicle windows, and simply to heat the car interior more quickly to a higher temperature. The other reason is that the outside air may not be very clean, for example, in heavy congested traffic.

8.14.3 Heater blower motors

The motors used to increase airflow are simple permanent magnet two brush motors. The blower fan is often the centrifugal type, and in many cases, the blades are positioned asymmetrically to reduce resonant noise. Varying the voltage supplied controls motor speed. This is achieved by using dropping resistors. The speed in some cases is made 'infinitely' variable, by the use of a variable resistor. In most cases, the motor is controlled to three or four set speeds.

Figure 8.72 shows a circuit diagram typical of a three-speed control system. The resistors are usually wire wound and are placed in the air stream to prevent overheating. These resistors will have low values in the region of 1 Ω or less (Figure 8.73).

8.14.4 Electronic heating control

Most vehicles that have electronic control of the heating system also include air conditioning, which is covered in the next section. However, a short description at this stage will help to lead into the more complex systems.

This system requires control of the blower motor, blend flap, direction flaps and the fresh or recirculated air flap. The technique involves one or a number of temperature sensors suitably positioned in the vehicle interior, to provide information for the ECU. The ECU responds to information received from these sensors and sets the controls to their optimum positions. The whole arrangement is in fact a simple closed loop feedback system with the air temperature closing the loop. The ECU has to compare the position of the temperature control switch with the information that is supplied by the sensors and either cool or heat the car interior as required.



Figure 8.73 Blower motor and fan

8.14.5 Air conditioning introduction

A vehicle f tted with air conditioning allows the temperature of the cabin to be controlled to the ideal or most comfortable value determined by the ambient conditions. The system as a whole still utilises the standard heating and ventilation components, but with the important addition of an evaporator, which both cools and dehumidif es the air.

Air conditioning can be manually controlled or, as is not often the case, combined with some form of electronic control. The system as a whole can be thought of as a type of refrigerator or heat exchanger. Heat is removed from the car interior and dispersed to the outside air. To understand the principle of refrigeration, the following terms and def nitions will be useful.

- Heat is a form of energy.
- Temperature means the degree of heat of an object.
- Heat will only f ow from a higher to a lower temperature.
- Heat quantity is measured in 'calories' (more often kcal).
- 1 kcal heat quantity changes the temperature of 1 kg of liquid water by 1 °C.
- Change of state is a term used to describe the changing of a solid to liquid, a liquid to a gas, a gas to a liquid or a liquid to a solid.
- Evaporation is used to describe the change of state from a liquid to a gas.
- Condensation is used to describe the change of state from gas to liquid.
- Latent heat describes the energy required to evaporate a liquid without changing its temperature (breaking of molecular bonds), or the amount of heat given off when a gas condenses back into a liquid without changing temperature (making of molecular bonds).

Latent heat in the change of state of a refrigerant is the key to air conditioning. A simple example of this is that if you put a liquid such as methylated spirits on your hand it feels cold. This is because it evaporates and the change of state (liquid to gas) uses heat from your body. This is why the process is often thought of as 'unheating' rather than cooling.

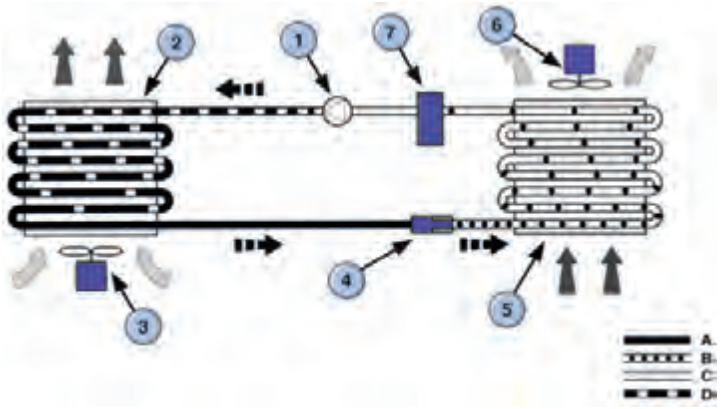


Figure 8.74 AC system layout: 1 – compressor; 2 – condenser; 3 – auxiliary fan (depending on model); 4 – fixed orifice tube; 5 – evaporator; 6 – heater/air conditioning blower; 7 – suction accumulator/drier; A – high-pressure warm liquid; B – low-pressure cool liquid; C – low-pressure, gaseous and cool; D – high-pressure, gaseous and hot (Source: Ford Motor Company)



Figure 8.75 AC components

The refrigerant used in many air conditioning systems is known as R134A. This substance changes state from liquid to gas at −26.3 °C. R134A is hydrofluorocarbon (HFC) based rather than chlorofluorocarbon (CFC), due to the problems with atmospheric ozone depletion associated with CFC-based refrigerants. A key to understanding refrigeration is to remember that low-pressure refrigerant will have low temperature, and high-pressure refrigerant will have a high temperature.

Figure 8.74 shows the basic principle of an air conditioning – or refrigeration – system. The basic components are the evaporator, condenser and pump or compressor. The evaporator is situated in the car; the condenser is outside the car, usually in the air stream; and the compressor is driven by the engine.

As the pump operates, it will cause the pressure on its intake side to fall, which will allow the refrigerant in the evaporator to evaporate and draw heat from the vehicle interior. The high pressure or output of the pump is connected to the condenser. The pressure causes the refrigerant to condense (in the condenser), thus giving off heat outside the vehicle as it changes state. Figure 8.75 shows some typical components of an air conditioning system.

Key fact

On an AC system, the evaporator is situated in the car; the condenser is outside the car, usually in the air stream; and the compressor is driven by the engine.

8.14.6 Air conditioning overview

The operation of the system is a continuous cycle. The compressor pumps low pressure but heatladen vapour from the evaporator, compresses it and pumps it as a superheated vapour under high pressure to the condenser. The temperature of the refrigerant at this stage is much higher than the outside air temperature, hence it gives up its heat via the f ns on the condenser as it changes state back to a liquid.

This high-pressure liquid is then passed to the receiver drier where any vapour which has not yet turned back to a liquid is stored, and a desiccant bag removes any moisture (water) that is contaminating the refrigerant. The high-pressure liquid is now passed through the thermostatic expansion valve and is converted back to a low-pressure liquid as it passes through a restriction in the valve into the evaporator. This valve is the element of the system that controls the refrigerant f ow and hence the amount of cooling provided. As the liquid changes state to a gas in the evaporator, it takes up heat from its surroundings, thus cooling or 'unheating' the air that is forced over the f ns. The low-pressure vapour leaves the evaporator returning to the pump, thus completing the cycle.

If the temperature of the refrigerant increases beyond certain limits, condenser cooling fans can be switched in to supplement the ram air effect. A safety switch is f tted in the high-pressure side of most systems. It is often known as a high–low pressure switch, as it will switch off the compressor if the pressure is too high due to a component fault, or if the pressure is too low due to a leakage, thus protecting the compressor.

8.14.7 Automatic temperature control

Full temperature control systems provide a comfortable interior temperature in line with the passenger controlled input. The ECU has full control of fan speed, air distribution, air temperature, fresh or recirculated air and the air conditioning pump. These systems will soon be able to control automatic demist or defrost when reliable sensors are available. A single button currently will set the system to full defrost or demist.

A number of sensors are used to provide input to the ECU.

- Ambient temperature sensor mounted outside the vehicle to allow compensation for extreme temperature variation. This device is usually a thermistor.
- Solar light sensor mounted on the fascia panel. This device is a photodiode and allows a measurement of direct sunlight from which the ECU can determine whether to increase the air to the face vents.
- The in-car temperature sensors are simple thermistors but to allow for an accurate reading a small motor and fan can be used to take a sample of interior air and direct it over the sensing elements.
- A coolant temperature sensor is used to monitor the temperature of the coolant supplied to the heater matrix. This sensor is used to prevent operation of the system until coolant temperature is high enough to heat the vehicle interior.
- Driver input control switches.

The ECU takes information from all of the above sources and will set the system in the most appropriate manner as determined by the software. Control of the f aps can be either by solenoid controlled vacuum actuators or by small motors. The main blower motor is controlled by a heavy-duty power transistor and is constantly

Key fact

Control of the HVAC faps can be either by solenoid controlled vacuum actuators or by small motors.



Figure 8.76 Heated seat

variable. These systems are able to provide a comfortable interior temperature in exterior conditions ranging from −10 to +35 °C even in extreme sunlight.

8.14.8 Seat heating

The concept of seat heating is very simple. A heating element is placed in the seat, together with an on–off switch and a control to regulate the heat. However, the design of these heaters is more complex than first appears. The heater must meet the following criteria:

- The heater must only supply the heat loss experienced by the person's body.
- Heat is to be supplied only at the major contact points.
- Leather and fabric seats require different systems due to their different thermal properties.
- Heating elements must fit the design of the seat.
- The elements must pass the same rigorous tests as the seat, such as squirm, jounce and bump tests.

In order for the passengers (including the driver) to be comfortable, rigorous tests have been carried out to find the optimum heat settings and the best position for the heating elements. Many tests are carried out on new designs, using manikin with sensors attached, to measure the temperature and heat flow (Figure 8.76).

The cable used for most heating elements consists of multi-strand alloyed copper. This cable may be coated with tin or insulated as the application demands. The heating element is laminated and bonded between layers of polyurethane foam.

8.14.9 Screen heating

Heating of the rear screen involves a very simple circuit. The heating elements consist of a thin metallic strip bonded to the glass. When a current is passed through the elements, heat is generated and the window will defrost or demist. This circuit can draw high current, 10–15 A being typical. Because of this, the circuit will often contain a timer relay to prevent the heater being left on for too long. The timer will switch off after 10–15 minutes. The elements are usually positioned to defrost the main area of the screen and the rest position of the rear wiper blade if fitted (Figure 8.77).

Front windscreen heating is being introduced on many vehicles. This of course presents more problems than the rear screen, as vision must not be obscured. The technology, drawn from the aircraft industry, involves very thin wires cast in to the glass. As with the heated rear window, this device can consume a large current and is operated by timer relay.

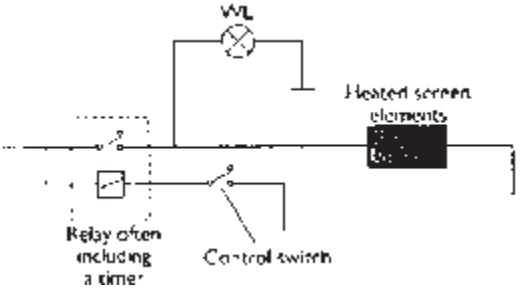


Figure 8.77 Screen heating circuit

8.15 Diagnostics – HVAC

8.15.1 Testing procedure (Figure 8.78)

The process of checking an air conditioning system is broadly as presented in Figure 8.79.

Safety f rst

Warning: Do not work on the refrigerant side of air conditioning systems unless you have been trained and have access to suitable equipment.

8.15.2 Air conditioning fault diagnosis table

Symptom	Possible fault
After stopping the compressor, pressure falls quickly to approximately 195kPa and then falls gradually	Air in the system, or if no bubbles are seen in the sight glass as the condenser is cooled with water, then excessive refrigerant may be the fault
Discharge pressure low	Fault with the compressor, or if bubbles are seen, low refrigerant
Discharge temperature is lower than normal	Frozen evaporator
Suction pressure too high	High pressure valve fault, excessive refrigerant or expansion valve open too long
Suction and discharge pressure too high	Excessive refrigerant in the system or condenser not working due to fan fault or clogged dirt
Suction and discharge pressure too low	Clogged or kinked pipes
Refrigerant loss	Oily marks (from the lubricant in the refrigerant) near joints or seals indicate leaks



Figure 8.78 Circuit voltage testing

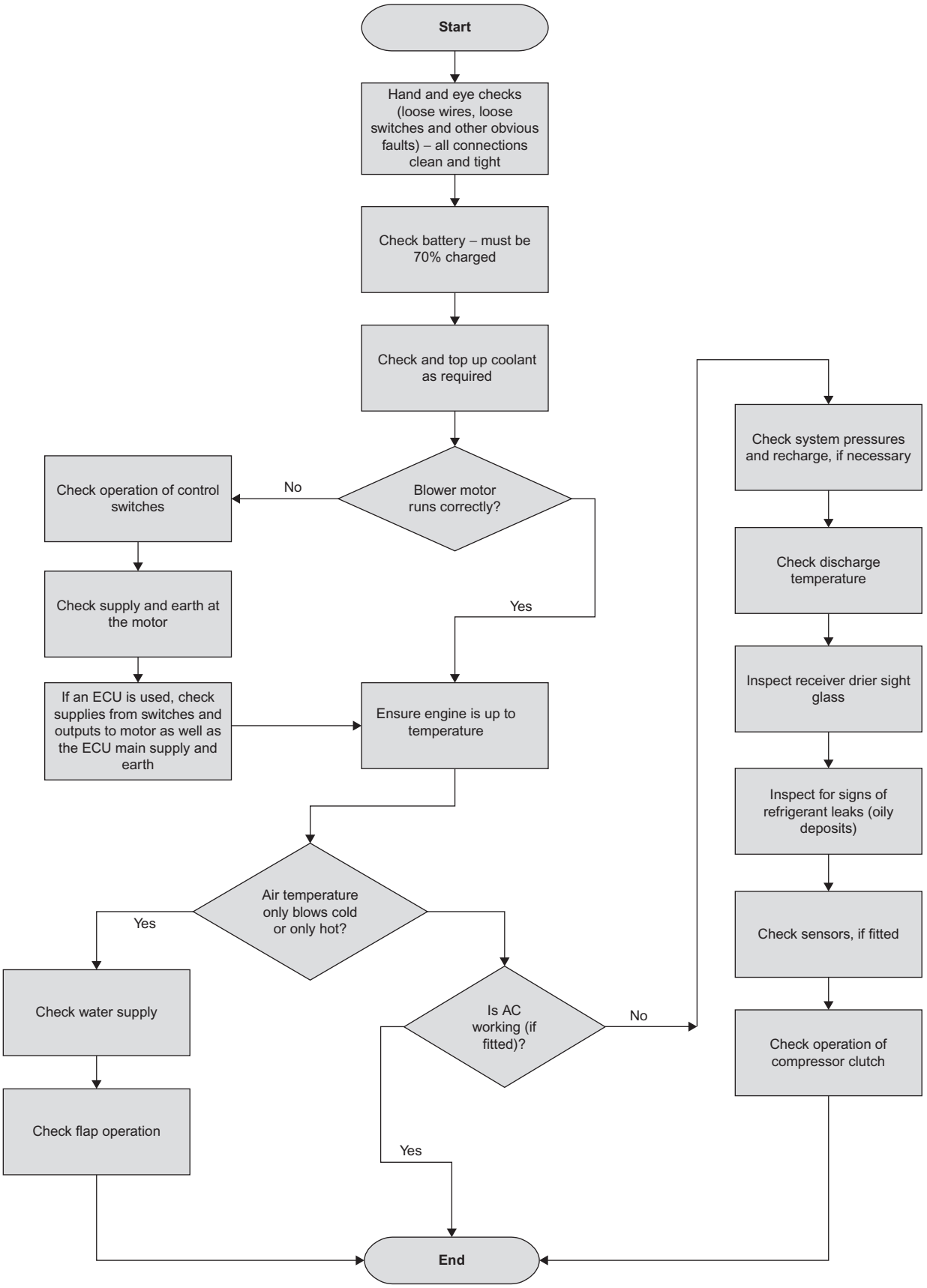


Figure 8.79 HVAC system diagnosis chart

8.15.3 Heating and ventilation fault diagnosis table

Symptom	Possible fault
Booster fan not operating at any speed	Open circuit fuse/supply/earth Motor inoperative/seized Dropping resistor(s) open circuit Switch open circuit Electronic speed controller not working
Booster fan only works o full speed	Dropping resistor(s) open circuit Switch open circuit Electronic speed controller not working
Control fap(s) will not move	Check vacuum connections (many work by vacuum-operated actuators) Inspect cables
No hot air	Matrix blocked Blend fap stuck
No cold air	Blend fap stuck Blocked intake
Reduced temperature when set to 'Hot'	Cooling system thermostat stuck open Heater matrix partially blocked Control fap not moving correctly

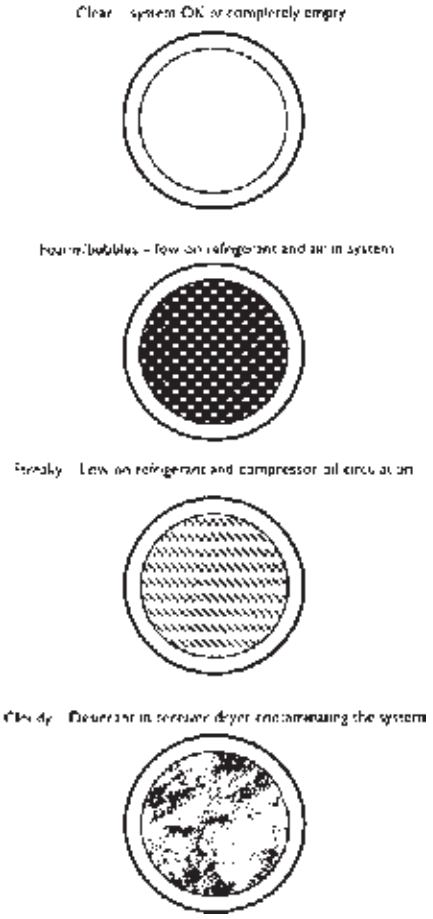


Figure 8.80 AC receiver drier sight glass

8.15.4 Air conditioning receiver

A very useful guide to diagnostics is the receiver drier sight glass. Figure 8.80 shows four possible symptoms and suggestions as to the possible fault.

8.16 Cruise control

8.16.1 Introduction

Cruise control is the ideal example of a closed loop control system as shown in Figure 8.81. The purpose of cruise control is to allow the driver to set the vehicle speed and let the system maintain it automatically. The system reacts to the measured speed of the vehicle and adjusts the throttle accordingly. The reaction time is important so that the vehicle's speed does not feel as if it is surging up and down.

Other facilities are included such as allowing the speed to be gradually increased or decreased at the touch of a button. Most systems also remember the last set

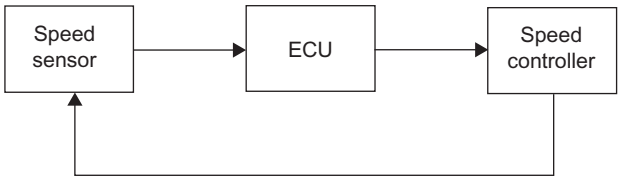


Figure 8.81 Cruise control – closed control loop negative feedback

Def nition

Negative feedback acts to reduce the input signal that caused it, is also known as a self-correcting or balancing loop. Negative feedback loops are goal seeking, for example, a temperature sensor in a system that compares actual temperature with desired temperature and acts to reduce the difference.

Table 8.3 Cruise control components

Actuator	A number of methods are used to control the throttle position. Vehicles fitted with drive by wire systems allow the cruise control to operate the same actuator. A motor can be used to control the throttle cable or in many cases a vacuum-operated diaphragm is used which three simple valves control
Main switch and warning lamp	This is a simple on/off switch located in easy reach of the driver on the dashboard. The warning lamp can be part of this switch or part of the main instrument display as long as it is in the driver's field of vision
Set and resume switches	These are fitted either on the steering wheel or on a stalk from the steering column. When they are part of the steering wheel slip rings are needed to transfer the connection. The 'set' button programmes the speed into memory and can also be used to increase the vehicle and memory speed. The 'resume' button allows the vehicle to reach its last set speed or to temporarily deactivate the control
Brake switch	This switch is very important as it would be dangerous braking if the cruise control system was trying to maintain the vehicle speed. This switch is normally of superior quality and fitted in place or as a supplement to the brake light switch activated by the brake pedal. Adjustment of this switch is important
Clutch or automatic gearbox switch	The clutch switch is fitted in a similar manner to the brake switch. It deactivates the cruise system to prevent the engine speed increasing if the clutch is pressed. The automatic gearbox switch will only allow the cruise to be engaged when it is in the 'drive' position. This is again to prevent the engine overspeeding if the cruise tried to accelerate to a high road speed with the gear selector in '1' or '2' position. The gearbox will still change gear if accelerating back up to a set speed as long as it 'knows' top gear is available
Speed sensor	This will often be the same sensor that is used for the speedometer. If not, several types are available; the most common produces a pulsed signal, the frequency of which is proportional to the vehicle speed
Headway sensor	Only used on 'active' systems, this device uses radar or light to sense the distance from the vehicle in front

speed and will resume this again at the touch of a button. To summarise and to add further refinements, the following is the list of functional requirements for a good cruise control system:

- hold the vehicle speed at the selected value;
- hold the speed with minimum surging;
- allow the vehicle to change speed;
- relinquish control immediately after the brakes are applied;
- store the last set speed;
- contain built-in safety features.

8.16.2 System description

The main switch switches on the cruise control; this in turn is ignition controlled. Most systems do not retain the speed setting in memory when the main switch



Figure 8.82 Headway sensor and control electronics

has been turned off. Operating the 'set' switch programs the memory, but this will normally work only if conditions similar to the following are met:

- vehicle speed is greater than 40 km/h;
- vehicle speed is less than 12 km/h;
- change of speed is less than 8 km/h/s;
- automatics must be in 'drive';
- brakes or clutch are not being operated;
- engine speed is stable.

Once the system is set, the speed is maintained to within approximately 3–4 km/h until it is deactivated by pressing the brake or clutch pedal, pressing the 'resume' switch or turning off the main control switch. The last 'set' speed is retained in memory except when the main switch is turned off.

If the cruise control system is required again, then either the 'set' button will hold the vehicle at its current speed or the 'resume' button will accelerate the vehicle to the previous 'set' speed. When cruising at a set speed, the driver can press and hold the 'set' button to accelerate the vehicle until the desired speed is reached when the button is released. If the driver accelerates from the set speed, to overtake for example, then, when the throttle is released, the vehicle will slow down until it reaches the last set position.

8.16.3 Components

The main components of a typical cruise control system are given in Table 8.3 (Figure 8.82).

8.17 Diagnostics – cruise control

8.17.1 Systematic testing

If the cruise control system will not operate then, considering the ECU as a black box, the procedure presented in Figure 8.83 should be followed.

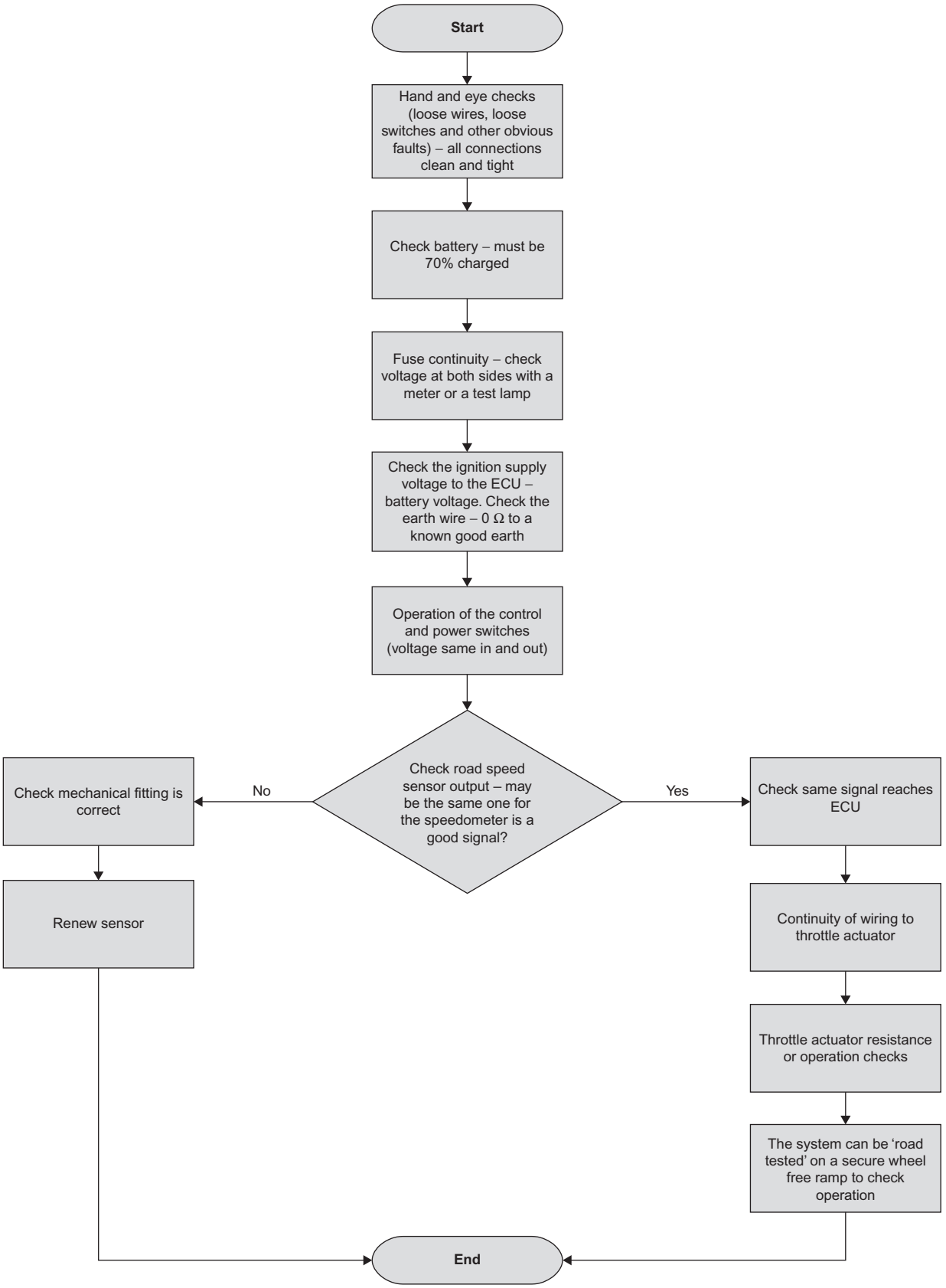


Figure 8.83 Cruise control fault diagnosis chart

8.17.2 Cruise control fault diagnosis table

Symptom	Possible fault
Cruise control will not se	Brake switch sticking on Safety valve/circuit fault Diaphragm holed Actuating motor open circuit or seized Steering wheel slip ring open circuit Supply/earth/fuse open circuit General wiring fault
Surging or uneven speec	Actuator cable out of adjustment ECU fault Engine/engine management fault

8.18 Airbags and belt tensioners

8.18.1 Introduction

Seat belt, seat belt tensioner and an airbag are at present the most effective restraint system in the event of a serious accident. At speeds in excess of 40 km/h, the seat belt alone is no longer adequate. The method becoming most popular for an airbag system is that of building most of the required components into one unit. This reduces the amount of wiring and connections, thus improving reliability. An important aspect is that some form of system monitoring must be built in, as the operation cannot be tested – it only works once.

Safety f rst

At speeds in excess of 40 km/h, the seat belt alone is no longer adequate.

The sequence of events in the case of a frontal impact at approximately 35 km/h, as shown in Figure 8.84, is as follows:

1. Driver in normal seating position prior to impact.
2. Approximately 15 ms after the impact the vehicle is strongly decelerated and the threshold for triggering the airbag is reached. The igniter ignites the fuel tablets in the inf ater.

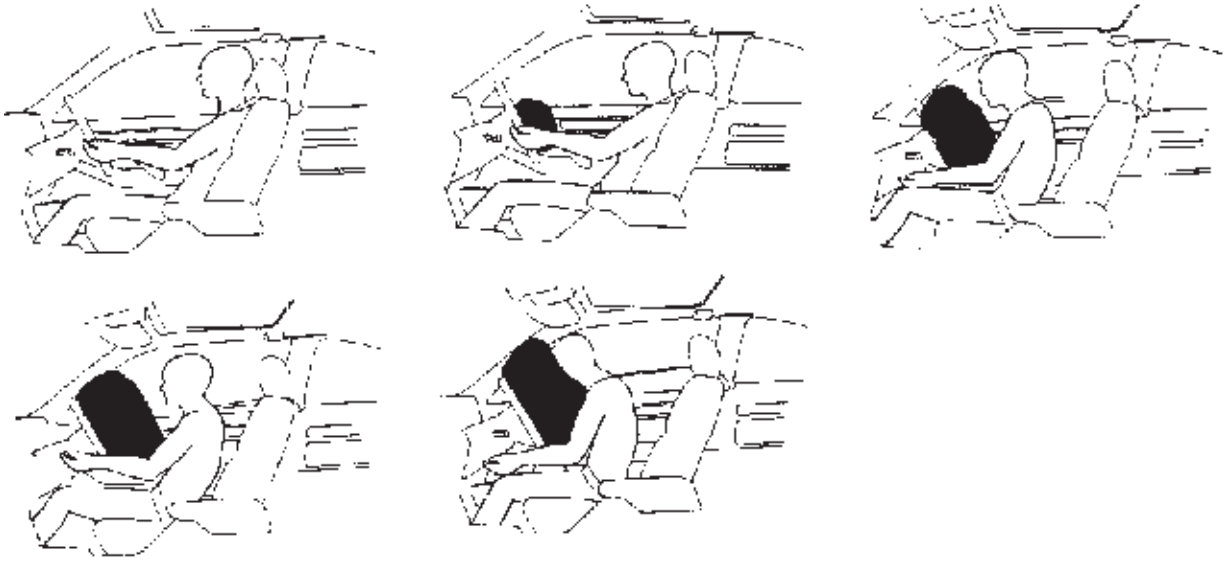


Figure 8.84 Airbag deployment

3 After approximately 30 ms, the airbag unfolds and the driver will have moved forward as the vehicle crumple zones collapse. The seat belt will have locked or been tensioned depending on the system.
4 At 40 ms after the impact the airbag will be fully inf ated and the driver's momentum will be absorbed by the airbag.
5 Approximately 120 ms after the impact the driver will be moved back into the seat and the airbag will have almost def ated through the side vents allowing driver visibility.

Passenger airbag events are similar to the above description. A number of arrangements are used with the mounting of all components in the steering wheel centre becoming the most popular. Nonetheless, the basic principle of operation is the same.

8.18.2 Components and circuit

The main components of a basic airbag system are as follows:

- driver and passenger airbags;
- warning light;
- passenger seat switches;
- pyrotechnic inf ater;
- igniter;
- crash sensor(s);
- ECU.

Key fact

The airbag is made of a nylon fabric with a coating on the inside.

The airbag is made of a nylon fabric with a coating on the inside. Prior to inf ation, the airbag is folded up under suitable padding which has specially designed break lines built in. Holes are provided in the side of the airbag to allow rapid def ation after deployment. The driver's air bag has a volume of approximately 60 L and the passenger airbag approximately 160 L. Figure 8.86 shows a steering wheel with an airbag f tted in the centre.

A warning light is used as part of the system monitoring circuit. This gives an indication of a potential malfunction and is an important part of the circuit. Some manufacturers use two bulbs for added reliability (Figure 8.85).

A seat switch on the passenger side may prevent deployment when not occupied. This may be more appropriate to side-impact airbags.

The pyrotechnic inf ater and the igniter can be considered together. The inf ater in the case of the driver is located in the centre of the steering wheel. It contains a number of fuel tablets in a combustion chamber. The igniter consists of charged capacitors, which produce the ignition spark. The fuel tablets burn very rapidly and produce a given quantity of nitrogen gas at a given pressure. This gas is forced into the airbag through a f lter and the bag inf ates breaking through the padding in the wheel centre. After deployment, a small amount of sodium hydroxide will be present in the airbag and vehicle interior. Personal protection equipment must be used when removing the old system and cleaning the vehicle interior.

The crash sensor can take a number of forms; these can be described as mechanical or electronic. The mechanical system works by a spring holding a roller in a set position until an impact above a predetermined limit provides enough force to overcome the spring, and the roller moves, triggering a micro switch. The switch is normally open with a resistor in parallel to allow the system to be monitored. Two switches similar to this may be used to ensure that the bag

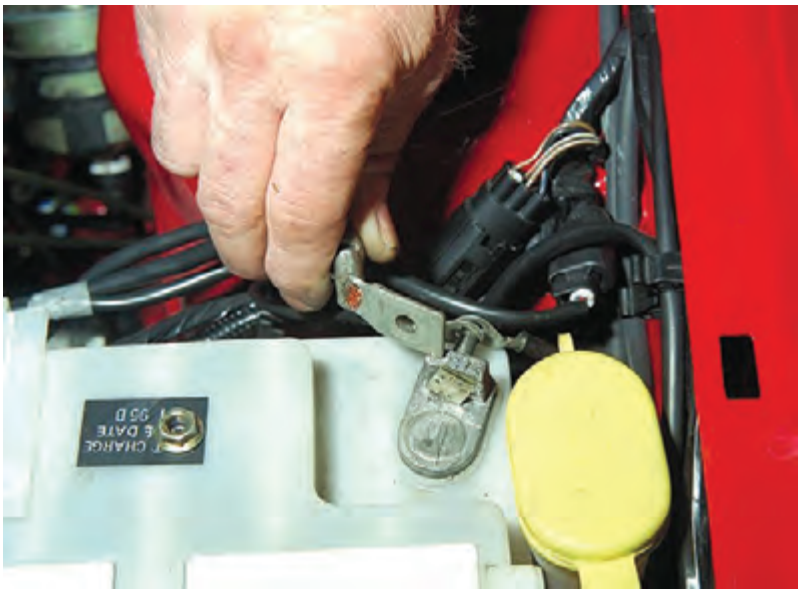


Figure 8.85 Remember – always disconnect the battery earth/ground if other components are to be removed (also check if a memory keeper should be fitted)



Figure 8.86 The driver's airbag is incorporated into the steering wheel

is deployed only in the case of suff cient frontal impact. Note the airbag is not deployed in the event of a roll over. The other main type of crash sensor can be described as an accelerometer. This will sense deceleration, which is negative acceleration (Figure 8.86).

The f nal component to be considered is the ECU or diagnostic control unit. When a mechanical-type crash sensor is used, in theory no electronic unit would be required. A simple circuit could be used to deploy the airbag when the sensor switch operated. However, it is the system monitoring or diagnostic part of the ECU which is most important. If a failure is detected in any part of the circuit, then the warning light will be operated. Up to f ve or more faults can be stored in the ECU memory, which can be accessed by blink code or serial fault readers. Conventional testing of the system with a multimeter and jump wires is not to be recommended as it might cause the airbag to deploy.

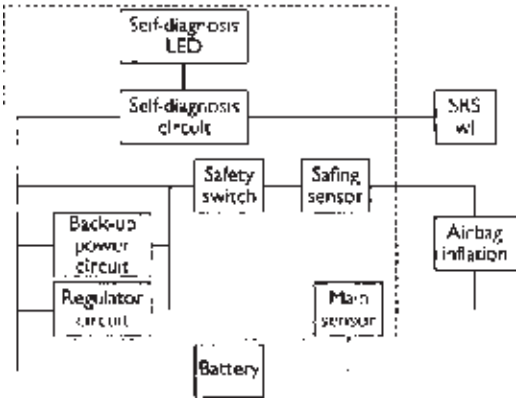


Figure 8.87 SRS block diagram



Figure 8.88 Seat belts and tensioner (Source: Volvo Media)

A block diagram of an airbag circuit is shown in Figure 8.87. Note the 'safing' circuit, which is a crash sensor that prevents deployment in the event of a faulty main sensor. A digital-based system using electronic sensors has approximately 10 ms at a vehicle speed of 50 km/h to decide if the supplementary restraint systems (SRS) should be activated. In this time, approximately 10 000 computing operations are necessary. Data for the development of these algorithms is based on computer simulations but digital systems can also remember the events during a crash allowing real data to be collected.

8.18.3 Seat belt tensioners

Taking the 'slack' out of a seat belt in the event of an impact is a good contribution to vehicle passenger safety. The decision to take this action is the same as for the airbag. The two main types are

- spring tension;
- pyrotechnic.

Key fact

A seatbelt tensioner unit must be replaced once deployed.

The mechanism used by one type of seat belt tensioner works by explosives. When the explosive charge is fired, the cable pulls a lever on the seat belt reel, which in turn tightens the belt. The unit must be replaced once deployed. This feature is sometimes described as anti-submarining (Figures 8.88 and 8.89).



Figure 8.89 The reason for SRS (Source: Saab Media)

8.19 Diagnostics – airbags and belt tensioners

8.19.1 Systematic testing

The only reported fault for airbags should be that the warning light is staying on. If an airbag has been deployed, then all the major components should be replaced. Some basic tests that can be carried out are presented in Figure 8.90.

Safety f rst

Warning: Careless or incorrect diagnostic work could deploy the airbag causing serious injyr Leave well alone if in any doubt.

8.19.2 Airbags and belt tensioners fault diagnosis table

Symptom	Possible cause
Warning light on	Wiring fault Fuse blown or removed ECU fault Crash sensor fault Igniter fault

Safety f rst

Warning: Do not carr out any electrical tests on the airbag circuit.

8.19.3 Deactivation and activation procedures

Airbag simulators are required to carry out diagnosis and testing of the airbag system. For the frontal airbag(s), this tool may be as simple as a 2.5 Ω resistor, used to simulate an airbag module connection to the system. Do not short circuit the airbag module connections with a jumper wire. If a jumper wire is used to short circuit the airbag module connections, a lamp fault code will be displayed and a diagnostic trouble code logged by the airbag control module.

Ford recommend the following procedure for the airbag system f tted to the Ford Focus.

Safety f rst

Warning: Do not work on airbag circuits unless fully trained.

8.19.3.1 Deactivation procedure

Warning: The backup power supply must be depleted before any work is carried out on the supplementary restraint system. Wait at least one minute after

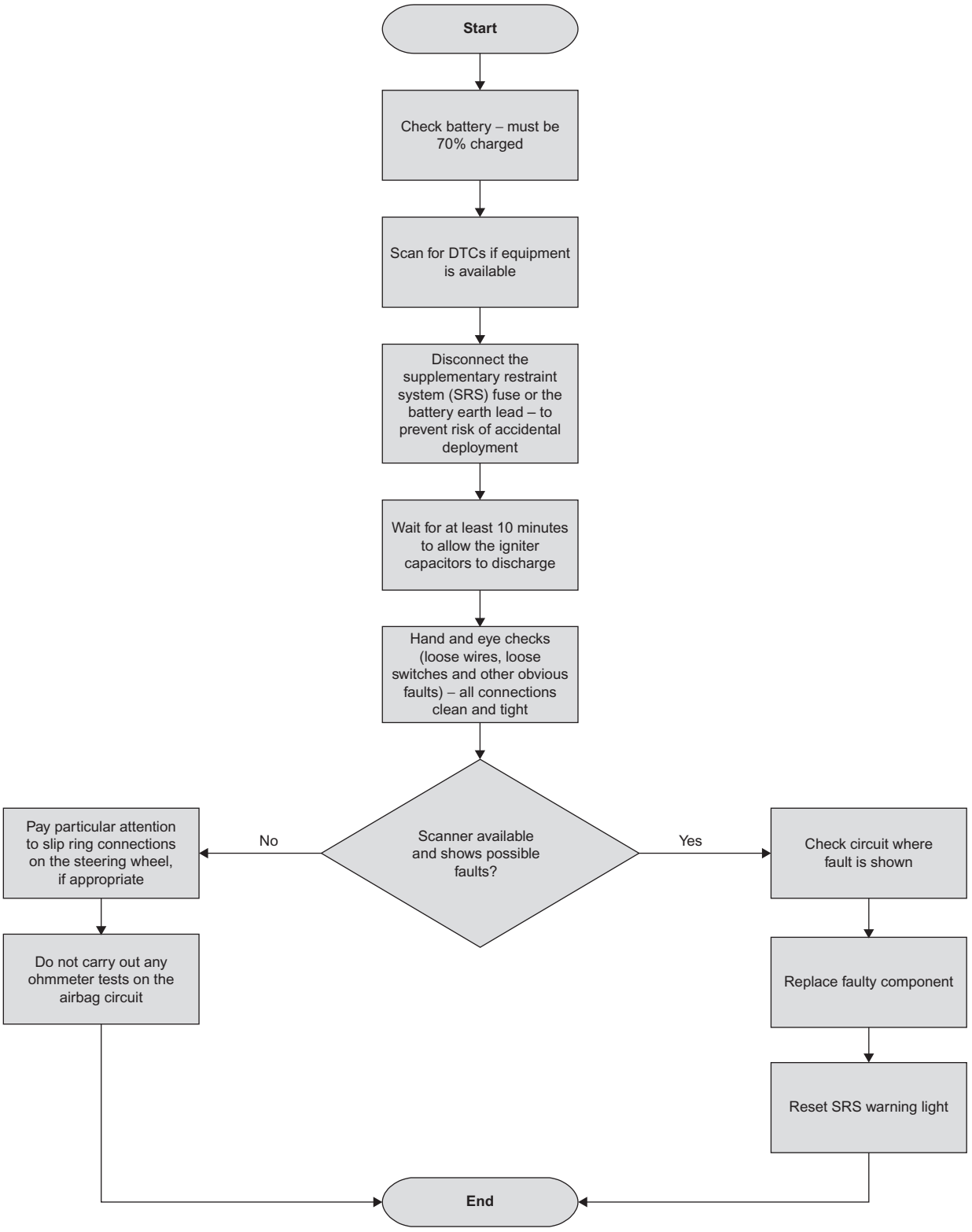


Figure 8.90 SRS diagnosis chart

disconnecting the battery ground cable. Failure to follow this instruction could cause accidental airbag deployment and may cause personal injury.

1 Disconnect the battery ground cable.
2 Wait one minute for the backup power supply in the Airbag Control Module to deplete its stored energy.

Warning: Place the airbag module on a ground wired bench, with the trim cover facing up to avoid accidental deployment. Failure to follow this instruction may result in personal injury.

1 Remove the driver airbag module from the vehicle.
2 Connect the airbag simulator to the sub-harness in place of the driver airbag module at the top of the steering column.
3 Remove the passenger airbag module.
4 Connect the airbag simulator to the harness in place of the passenger airbag module.
5 Disconnect the driver f ve-way under seat connector.
6 Connect the airbag simulator to driver f ve-way under seat f oor harness in place of the seat belt pre-tensioner and side airbag.
7 Disconnect the passenger f ve-way under seat connector.
8 Connect the airbag simulator to the passenger f ve-way under seat f oor harness in place of the seat belt pre-tensioner and side airbag.
9 Reconnect the battery ground cable.

8.19.3.2 Reactivation procedure

Warning: The airbag simulators must be removed and the airbag modules reconnected when reactivated to avoid non-deployment in a collision. Failure to follow this instruction may result in personal injury.

1 Disconnect the battery ground cable.
2 Wait one minute for the backup power supply in the Airbag Control Module to deplete its stored energy.
3 Remove the driver airbag simulator from the sub-harness at the top of the steering column.
4 Reconnect and install the driver airbag module.
5 Remove the passenger airbag simulator from the passenger airbag module harness.
6 Reconnect and install the passenger airbag module.
7 Remove the airbag simulator from the driver f ve-way under seat connector.
8 Reconnect the driver f ve-way under seat connector.
9 Remove the airbag simulator from the passenger f ve-way under seat connector.
10 Reconnect the passenger f ve-way under seat connector.
11 Reconnect the battery ground cable.
12 Prove out the system, repeat the self-test and clear the fault codes.

Note: This section is included as general guidance; do not assume it is relevant to all vehicles.

CHAPTER

Transmission systems

9.1 Manual transmission

9.1.1 Clutch

A clutch is a device for disconnecting and connecting rotating shafts. In a vehicle with a manual gearbox, the driver pushes down the clutch when changing gear to disconnect the engine from the gearbox. It also allows a temporary neutral position for, say, waiting at traff c lights and a gradual way of taking up drive from rest.

Key fact

A clutch is a device for disconnecting and connecting rotating shafts.

The clutch is made of two main parts: a pressure plate and a driven plate. The driven plate, often termed the clutch disc, is f tted on the shaft, which takes the drive into the gearbox. When the clutch is engaged, the pressure plate presses the driven plate against the engine f ywheel. This allows drive to be passed to the gearbox. Pushing down the clutch springs the pressure plate away, which frees the driven plate. The diaphragm-type clutch replaced an earlier type with coil springs as it has a number of advantages when used on light vehicles (Figures 9.1 and 9.2):



Figure 9.1 Clutch cover and pressure plate

Advanced Automotive Fault Diagnosis.
© 2012 Tom Denton. Published by Routledge. All rights reserved.



Figure 9.2 Clutch disc

Key fact

The clutch is made of two main parts: a pressure plate and a driven plate.

- not affected by high speeds (coil springs can be thrown outwards);
- low pedal force making for easy operation;
- light and compact;
- clamping force increases or at least remains constant as the friction lining wears.

The method of controlling the clutch is quite simple. The mechanism consists of either a cable or hydraulic system.

9.1.2 Manual gearbox

The driver changes the gears of a manual gearbox by moving a hand-operated lever called a gear stick or shift lever. All manual gearboxes have a neutral position; three, four or f ve forward gears; and a reverse gear. A few even have six forward gears now. The driver puts the gearbox into neutral as the engine is being started, or when a car is parked with the engine left running (Figure 9.3).

Key fact

Power travels in to the gearbox via the input shaft.

Power travels in to the gearbox via the input shaft. A gear at the end of this shaft drives a gear on another shaft called the countershaft or layshaft. A number of gears of various sizes are mounted on the layshaft. These gears drive other gears on a third motion shaft also known as the output shaft.

The gearbox produces various gear ratios by engaging different combinations of gears. For reverse, an extra gear called an idler operates between the countershaft and the output shaft. It turns the output shaft in the opposite direction to the input shaft.

Figure 9.4 shows the power f ows through a manual box in each of the different gears. Note how in each case (with the exception of reverse) the gears do not move. This is why this type of gearbox has become known as constant mesh. In other words, the gears are running in mesh with each other at all times. Dog clutches are used to select which gears will be locked to the output shaft.



Figure 9.3 Manual gearbox with a cable change mechanism (Source: Ford Media)

These clutches which are moved by selector levers incorporate synchromesh mechanisms.

A synchromesh mechanism is needed because the teeth of the dog clutches would clash if they met at different speeds. The system works like a friction-type cone clutch. The collar is in two parts and contains an outer toothed ring that is spring-loaded to sit centrally on the synchromesh hub. When the outer ring (synchroniser sleeve) is made to move by the action of the selector mechanism, the cone clutch is also moved because of the locking keys. The gear speeds up as the cones touch, thus allowing the dog clutches to engage smoothly. A baulking ring is f tted between the cone on the gear wheel and the synchroniser hub. This is to prevent engagement until the speeds are synchronised (Figure 9.5).

A detent mechanism is used to hold the selected gear in mesh. In most cases, this is just a simple ball and spring acting on the selector shaft(s). Gear selection interlocks are a vital part of a gearbox. These are to prevent more than one gear from being engaged at any one time. On the single rail (one rod to change the gears) gearbox shown in the f gure, the interlock mechanism is shown at the rear. As the rod is turned (side-to-side movement of the gear stick) towards f rst–second, third–fourth or f fth gear positions, the interlock will only engage with either the f rst–second, third–fourth or f fth gear selectors as appropriate. Equally when any selector clutch is in mesh the interlock will not allow the remaining selectors to change position.

Key fact

A synchromesh mechanism is needed because the teeth of the dog clutches would clash if they met at different speeds.

Key fact

Gear selection interlocks prevent more than one gear from being engaged at any one time.

Key fact

A detent mechanism is used to hold the selected gear in mesh.

9.1.3 Driveshafts and wheel bearings

Light vehicle driveshafts now fall into one of two main categories, the f rst being by far the most popular.

- **Driveshafts with constant velocity joints (FWD)** – transmit drive from the output of the f nal drive to each front wheel. They must also allow for suspension and steering movements.
- **Propshaft with universal joints (RWD) –** transmits drive from the gearbox output to the f nal drive in the rear axle. Drive then continues through the f nal

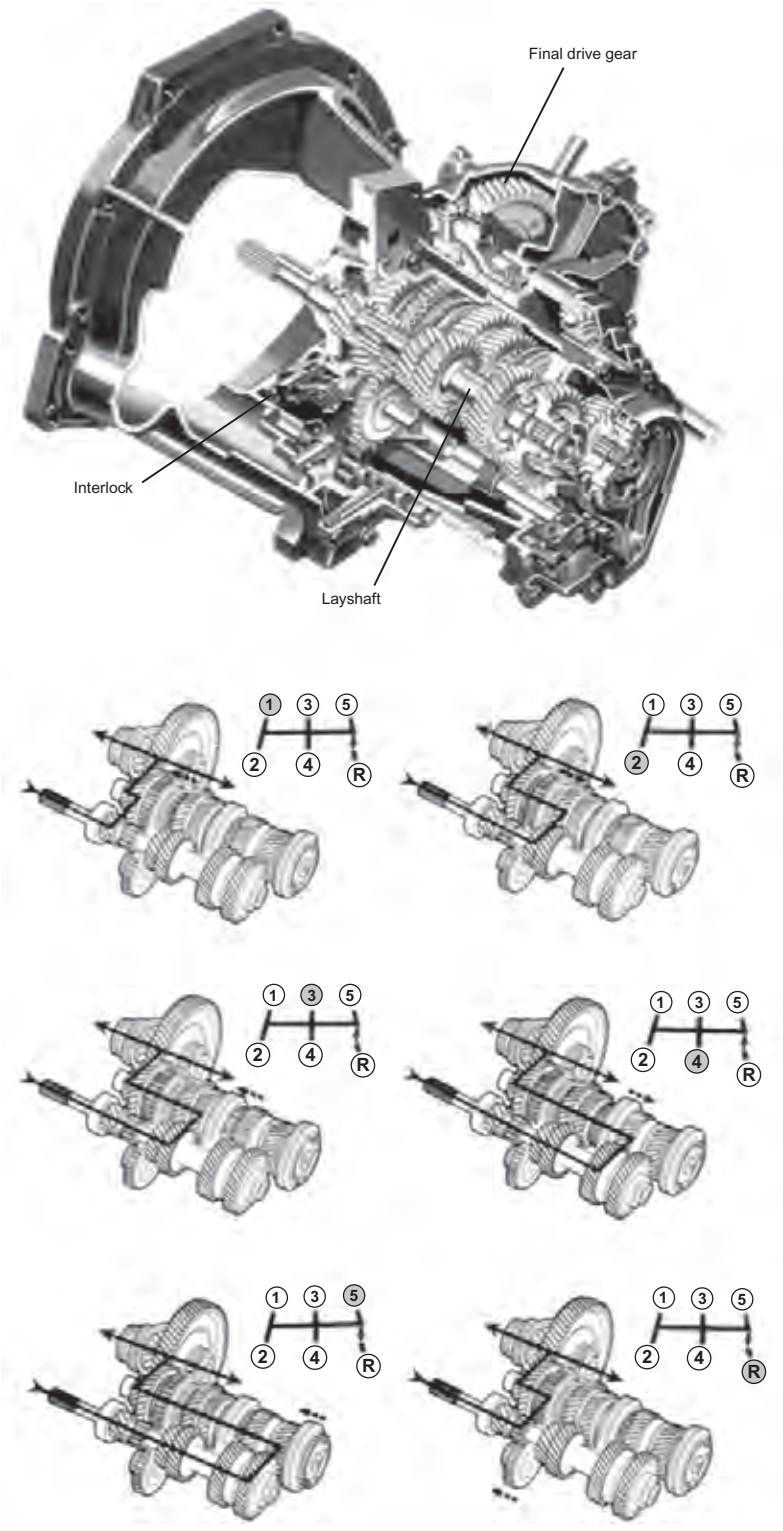


Figure 9.4 Five-speed manual gearbox and powerflows

drive and differential, via two half shafts to each rear wheel. The propshaft must also allow for suspension movements.

Wheel bearings are also very important. They allow smooth rotation of the wheel but must also be able to withstand high stresses such as from load in the vehicle and when cornering (Tables 9.1 and 9.2).

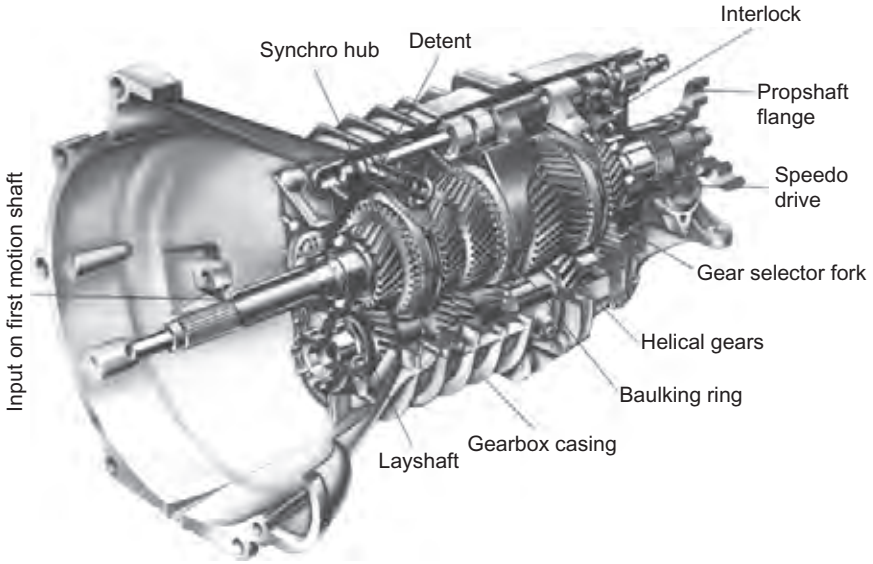


Figure 9.5 RWD manual gearbox

Table 9.1 Front bearings

Seal	Keep out dirt and water, and keep in the grease lubrication
Spacer	Ensures the correct positioning of the seal
Inner bearing	Supports the weight of the vehicle at the front, when still or moving. Ball bearings are used for most vehicles with specially shaped tracks for the balls. This is why the bearings can stand side loads when cornering
Swivel hub	Attachment for the suspension and steering as well as supporting the bearings
Outer bearing	As for inner bearing
Drive fange	Runs inside the centre race of the bearings. The wheel is bolted to this f

Table 9.2 Rear bearings

Stub axle	Solid mounted to the suspension arm, this stub axle in the centre of the two bearings
Seal	Keep out dirt and water, and keep in the grease lubrication
Inner bearing	Supports the weight of the vehicle at the rear when still or moving. Ball bearings are used for most vehicles with specially shaped tracks for the balls. This is why the bearings can stand side loads when cornering
Spacer	To ensure the correct spacing and pressure between the two bearings
Drum	For the brakes and attachment of the wheel
Outer bearing	As for inner bearing
Washer	The heavy washer acts as a face for the nut to screw against
Castle nut and split pin	Holds all parts in position securely. With this type of bearing, no adjustment is made because both bearings are clamped on to the spacer. Some older cars use tapered bearings and adjustment is very important
Grease retainer cap	Retains grease, but should not be overpacked. Also keeps out the dirt and water

9.1.4 Final drive and differential

Key fact

The final drive gears provide a fixed gear reduction.

Because of the speed at which an engine runs, and in order to produce enough torque at the road wheels, a fixed gear reduction is required. This is known as the final drive and consists of just two gears. These are fitted after the output of the gearbox, on front wheel drive, or in the rear axle after the propshaft on rear wheel drive vehicles. The gears also turn the drive through 90° on rear wheel drive vehicles. The ratio is normally about 4:1; in other words, when the gearbox output is turning at 4000 rpm, the wheels will turn at 1000 rpm.

Many cars now have a transverse engine, which drives the front wheels. The power of the engine therefore does not have to be carried through a right angle to the drive wheels. The final drive contains ordinary reducing gears rather than bevel gears.

The differential is a set of gears that divide the torque evenly between the two drive wheels. The differential also allows one wheel to rotate faster than the other does when necessary. When a car goes around a corner, the outside drive wheel travels further than the inside one. The outside wheel must therefore rotate faster than the inside one to cover the greater distance in the same time.

Some higher-performance vehicles use limited slip differentials. The clutch plates are connected to the two output shafts and hence if controlled will in turn control the amount of slip. This can be used to counteract the effect of one wheel losing traction when high power is applied.

Differential locks are used on many off-road type vehicles. A simple dog clutch or similar device prevents the differential action. This allows far better traction on slippery surfaces.

9.1.5 Four-wheel drive systems

Key fact

The transfer gearbox on some vehicles may also contain extra reduction gears for low ratio drive.

Four-wheel drive (4 WD) provides good traction on rough or slippery surfaces. Many cars are now available with 4 WD. In some vehicles, the driver can switch between 4 WD and two-wheel drive (2 WD). A vehicle with 4 WD delivers power to all four wheels. A transfer box is used to distribute the power between the front and rear wheels:

- transfer gearbox to provide an extra drive output;
- differential on each axle to allow cornering speed variations;
- centre differential to prevent wind-up between the front and rear axles;
- extra drive shafts to supply drive to the extra axle (Figure 9.6).

One problem to overcome, however, with 4 WD is that if three differentials are used, then the chance of one wheel slipping actually increases. This is because the drive will always be transferred to the wheel with least traction – like running a 2 WD car with one driving wheel jacked up. To overcome this problem and take advantage of the extra traction available, a viscous coupling is combined with an epicyclic gear train to form the centre differential.

The drive can now be distributed proportionally. A typical value is approximately 35% to the front and 65% to the rear wheels. However, the viscous clutch coupling acts so that if a wheel starts to slip, the greater difference in speed across the coupling will cause more friction and hence more drive will pass through the coupling. This tends to act so that the drive is automatically distributed to the most effective driving axle. A ‘Hyvo’ or silent chain drive is often used to drive from the transfer box.



Figure 9.6 4 WD transmission layout (Source: Ford Media)

9.2 Diagnostics – manual transmission

9.2.1 Systematic testing

If the reported fault is a slipping clutch, proceed as follows:

1 Road test to conf rm when the fault occurs.
2 Look for oil leaking from the bell housing or general area of the clutch. Check adjustment if possible.
3 If adjustment is correct, then the clutch must be examined.
4 In this example, the clutch assembly must be removed for visual examination.
5 Replace parts as necessary; this is often done as a kit comprising the clutch plate and cover as well as a bearing in some cases.
6 Road test and check operation of all the transmission.

9.2.2 Test equipment

Stethoscope

This is a useful device that can be used in a number of diagnostic situations. In its basic form, it is a long screwdriver. The probe (or screwdriver blade) is placed near the suspected component such as a bearing. The ear piece (or screwdriver handle placed next to the ear) amplif es the sound. Take care though; even a good bearing can sound rough using this method. Compare a known good noise with the suspected one (Figure 9.7).

Safety f rst

Note: You should always refer to the manufacturer's instructions appropriate to the equipment you are using.

9.2.3 Test results

Some of the information you may have to get from other sources such as data books or a workshop manual is listed in the following table:

Test carried out	Information required
Backlash or freeplay	Backlash data is often given, as the distance component will move. The backlash between two gears, for example, should be very small
Overdrive operation	Which gears the overdrive is meant to operate in



Figure 9.7 Stethoscope

9.2.4 Manual transmission fault diagnosis table 1

Symptom	Possible causes or faults	Suggested action
Clutch slipping	Clutch worn out Adjustment incorrect Oil contamination	Renew Adjust or check auto-adjuster Rectify oil leak – clutch may also need to be renewed
Jumps out of gear	Gearbox detent fault	Gearbox may require overhaul
Noisy when changing gear	Synchromesh worn	Gearbox may require overhaul
Rapid knocking noise when cornering	Driveshaft CV joints worn or without lubrication	Renew or lubricate joint. Ensure gaiter is in place and in good condition
Whining noise	Wheel bearing worn Other bearings	Renew Investigate and renew if possible
Difficult to change gear	Clutch out of adjustment Clutch hydraulic fault Gearbox selectors worn	Adjust or check auto-adjuster Check system for air and/or leaks Gearbox may require overhaul

9.2.5 Manual gearbox fault diagnosis table 2

Symptom	Possible cause
Noisy in a particular gear (with engine running)	Damaged gear Worn bearing
Noisy in neutral (with engine running)	Input shaft bearings worn (goes away when clutch is pushed down?) Lack of lubricating oil Clutch release bearing worn (gets worse when clutch is pushed down?)
Difficult to engage gears	Clutch problem Gear linkage worn or not adjusted correctly Work synchromesh units Lack of lubrication
Jumps out of gear	Gear linkage worn or not adjusted correctly Worn selector forks Detent not working Weak synchromesh units
Vibration	Lack of lubrication Worn bearings Mountings loose
Oil leaks	Gaskets leaking Worn seals

9.2.6 Clutch faults diagnosis table

Symptom	Possible cause
No pedal resistance	Broken cable Air in hydraulic system Hydraulic seals worn Release bearing or fork broken Diaphragm spring broken
Clutch does not disengage	As above Disc sticking in gearbox splines Disc sticking to flywheel Faulty pressure plate
Clutch slip	Incorrect adjustment Worn disc linings Contaminated linings (oil or grease) Faulty pressure plate
Judder when engaging	Contaminated linings (oil or grease) Worn disc linings Distorted or worn pressure plate Engine mountings worn, loose or broken Clutch disc hub splines worn
Noisy operation	Broken components Release bearing seized Disc cushioning springs broken
Snatching	Disc cushioning springs broken Operating mechanism sticking (lubrication may be required)

9.2.7 Drive shafts fault diagnosis table

Symptom	Possible cause
Vibration	Incorrect alignment of propshaft joints Worn universal or CV joints Bent shaft Mountings worn
Grease leaking	Gaiters split or clips loose
Knocking noises	Dry joints Worn CV joints (gets worse on tight corners)

9.2.8 Final drive fault diagnosis table

Symptom	Possible cause
Oil leaks	Gaskets split Drive shaft oil seals Final drive output bearings worn (drive shafts drop and cause leaks)
Noisy operation	Low oil level Incorrect pre-load adjustment Bearings worn
Whining noise	Low oil level Worn differential gears

9.3 Automatic transmission

9.3.1 Introduction

An automatic gearbox contains special devices that automatically provide various gear ratios, as they are needed. Most automatic gearboxes have three or four forward gears and reverse. Instead of a gearstick, the driver moves a lever called a selector. Some automatic gearboxes have selector positions for park, neutral, reverse, drive, 2 and 1 (or 3, 2 and 1 in some cases). Others just have drive, park and reverse. The engine will only start if the selector is in either the park or neutral position. In park, the drive shaft is locked so that the drive wheels cannot move. It is now quite common when the engine is running to be able to move the selector out of park only if you are pressing the brake pedal. This is a very good safety feature as it prevents sudden movement of the vehicle.

Safety f rst

The selector will not move out of park unless you are pressing the brake pedal on many cars. This is a very good safety feature as it prevents sudden movement of the vehicle.

For ordinary driving, the driver moves the selector to the drive position. The transmission starts out in the lowest gear and automatically shifts into higher gears as the car picks up speed. The driver can use the lower positions of the gearbox for going up or down steep hills or driving through mud or snow. When in position 3, 2 or 1, the gearbox will not change above the lowest gear specif ed.

9.3.2 Torque converter operation

The torque converter is a device that almost all automatic transmissions now use. It delivers power from the engine to the gearbox like a basic f uid f ywheel but also increases the torque when the car begins to move. The torque converter resembles a large doughnut sliced in half. One half, called the pump impeller, is bolted to the drive plate or f ywheel. The other half, called the turbine, is connected to the gearbox input shaft. Each half is lined with vanes or blades. The pump and the turbine face each other in a case f lled with oil. A bladed wheel called a stator is f tted between them.

The engine causes the pump to rotate and throw oil against the vanes of the turbine. The force of the oil makes the turbine rotate and send power to the transmission. After striking the turbine vanes, the oil passes through the stator and returns to the pump. When the pump reaches a specif c rate of rotation, a reaction between the oil and the stator increases the torque. In a f uid f ywheel, oil returning to the impeller tends to slow it down. In a torque converter, the stator or reactor diverts the oil towards the centre of the impeller for extra thrust. Figure 9.8 shows a gearbox with a cutaway torque converter.

When the engine is running slowly, the oil may not have enough force to rotate the turbine. But when the driver presses the accelerator pedal, the engine runs faster and so does the impeller. The action of the impeller increases the force of the oil. This force gradually becomes strong enough to rotate the turbine and move the vehicle. A torque converter can double the applied torque when moving off from rest. As engine speed increases, the torque multiplication tapers off until at cruising speed when there is no increase in torque. The reactor or stator then freewheels on its one-way clutch at the same speed as the turbine.

Key fact

To improve effciency, many transmissions now include a lock-up clutch.

The f uid f ywheel action reduces eff ciency because the pump tends to rotate faster than the turbine. In other words, some slip will occur (approximately 2%). To improve eff ciency, many transmissions now include a lock-up clutch. When the pump reaches a specif c rate of rotation, this clutch locks the pump and turbine together, allowing them to rotate as one.

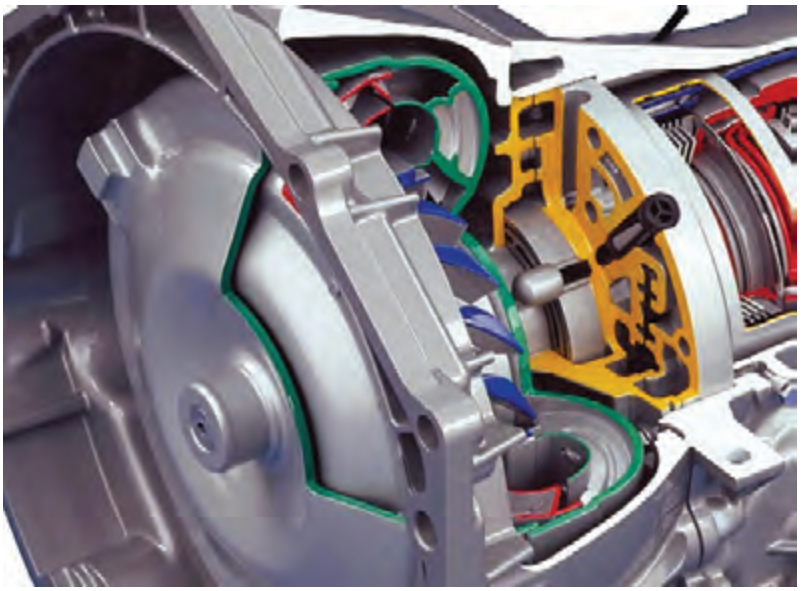


Figure 9.8 Cutaway torque converter (green, red and blue)

9.3.3 Epicyclic gearbox operation

Epicyclic gears are a special set of gears that are part of most automatic gearboxes. They consist of three elements:

1. a sun gear, located in the centre;
2. the carrier that holds two, three or four planet gears, which mesh with the sun gear and revolve around it;
3. an internal gear or annulus is a ring with internal teeth, which surrounds the planet gears and meshes with them.

Any part of a set of planetary gears can be held stationary or locked to one of the others. This will produce different gear ratios. Most automatic gearboxes have two sets of planetary gears that are arranged in line. This provides the necessary number of gear ratios. The appropriate elements in the gear train are held stationary by a system of hydraulically operated brake bands and clutches. These are worked by a series of hydraulically operated valves in the lower part of the gearbox. Oil pressure to operate the clutches and brake bands is supplied by a pump. The supply for this is the oil in the sump of the gearbox (Figure 9.9).

Key fact

Any part of a set of planetary gears can be held stationary or locked to one of the others.

Unless the driver moves the gear selector to operate the valves, automatic gear changes are made depending on just two factors:

1. **throttle opening** – a cable is connected from the throttle to the gearbox;
2. **road speed** – when the vehicle reaches a set speed, a governor allows pump pressure to take over from the throttle.

The cable from the throttle also allows a facility known as ‘kick down’. This allows the driver to change down a gear, such as for overtaking, by pressing the throttle all the way down (Figure 9.10).

Key fact

Modern semi-automatic gearboxes have paddle change but also work in a fully automatic mode.

Many modern semi-automatic gearboxes now use gears in the same way as in manual boxes. The changing of ratios is similar to the manual operation except that hydraulic clutches and valves are used.

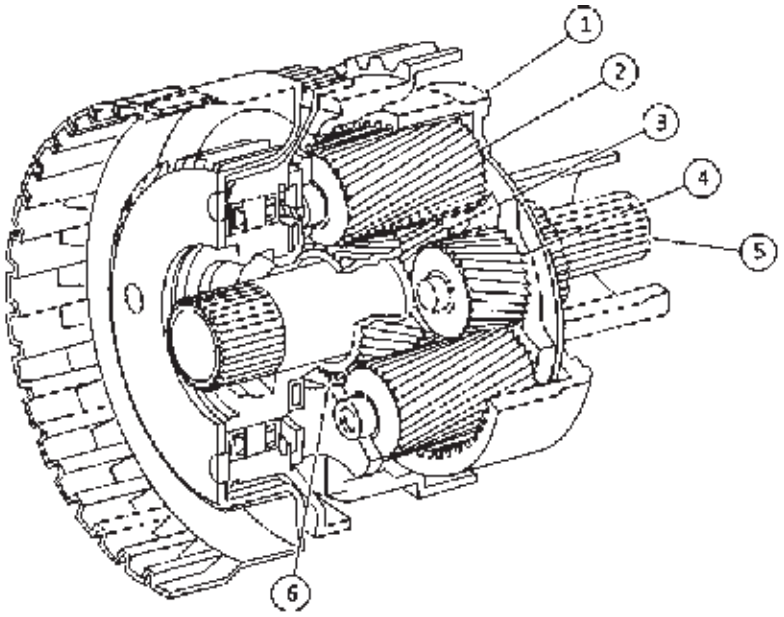


Figure 9.9 Ravigneaux gear set: 1 – ring gear; 2 – long planet gear; 3 – small planet gear; 4 – short planet gear; 5 – transmission input shaft; 6 – large sun gear (Source: Ford Motor Company)

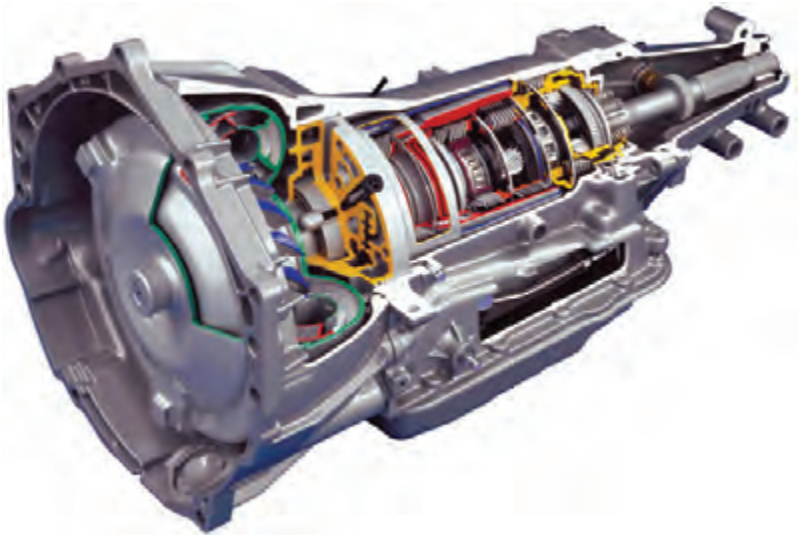


Figure 9.10 RWD automatic gearbox (Source: GM Media)

9.3.4 Constantly variable transmission

Def nition

CVT: Constantly variable transmission.

Figure 9.11 shows a constantly variable transmission (CVT). This kind of automatic transmission uses two pairs of cone-shaped pulleys connected by a metal belt. The key to this system is the high friction drive belt.

The belt is made from high-performance steel and transmits drive by thrust rather than tension. The ratio of the rotations, often called the gear ratio, is determined by how far the belt rides from the centres of the pulleys. The transmission can produce an unlimited number of ratios. As the car changes speed, the ratio is

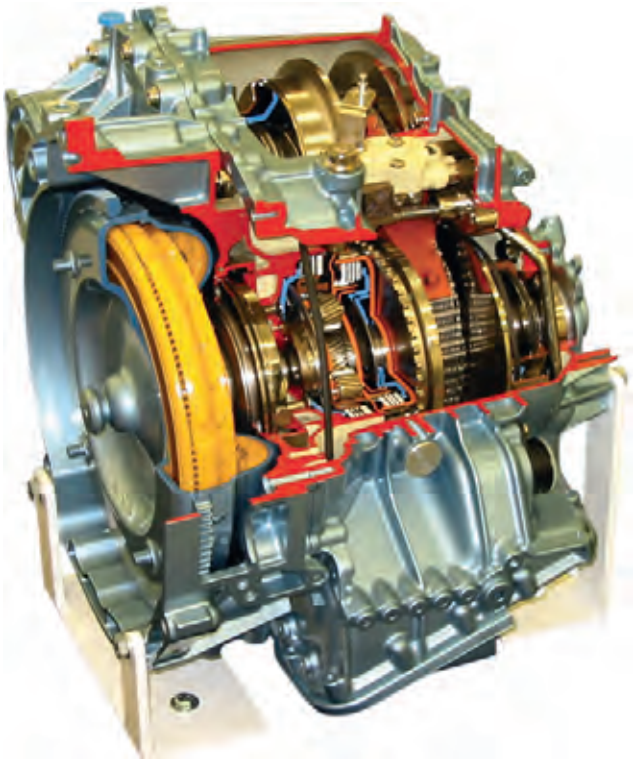


Figure 9.11 Constantly variable transmission(Source: Ford Media)

continuously adjusted. Cars with this system are said to use fuel more eff ciently than cars with set gear ratios. Within the gearbox hydraulic control is used to move the pulleys and hence change the drive ratio. An epicyclic gear set is used to provide a reverse gear as well as a f xed ratio.

Key fact

A CVT transmission can produce an unlimited number of ratios.

9.3.5 Electronic control of transmission

The main aim of electronically controlled automatic transmission (ECAT) is to improve on conventional automatic transmission in the following ways:

- gear changes should be smoother and quieter;
- improved performance;
- reduced fuel consumption;
- reduction of characteristic changes over system life;
- increased reliability.

The important points to remember are that gear changes and lock-up of the torque converter are controlled by hydraulic pressure. In an ECAT system, electrically controlled solenoid valves can inf uence this hydraulic pressure. Most ECAT systems now have a transmission ECU that is in communication with the engine control ECU (Figure 9.12).

With an ECAT system, the actual point of gearshift is determined from pre-programmed memory within the ECU. Data from other sensors is also taken into consideration. Actual gearshifts are initiated by changes in hydraulic pressure, which is controlled by solenoid valves.

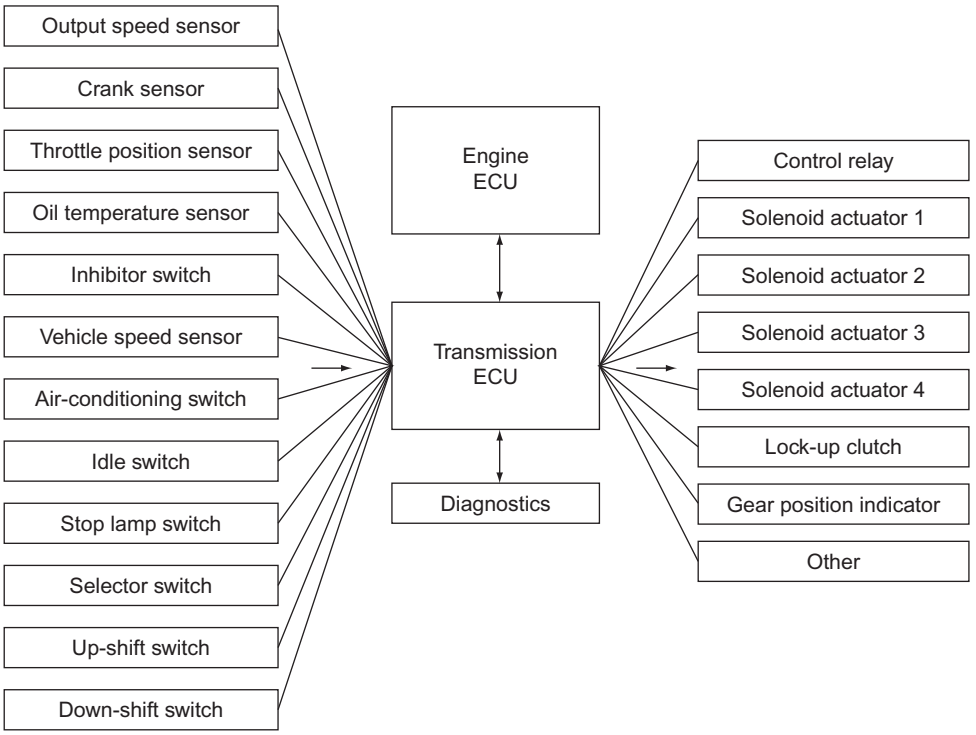


Figure 9.12 ECAT block diagram

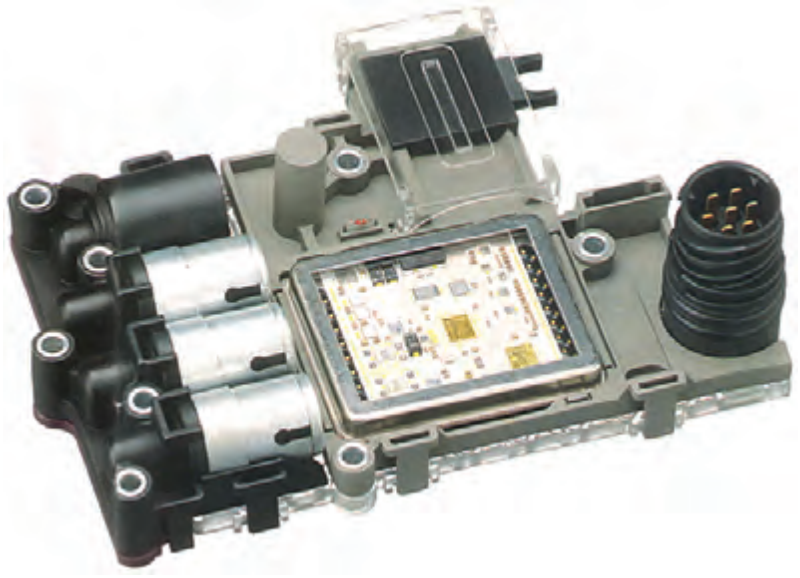


Figure 9.13 Electrohydraulic valve block

The two main control functions of this system are hydraulic pressure and engine torque. A temporary reduction in engine torque during gear shifting allows smooth operation. This is because the peak of gearbox output torque which causes the characteristic surge during gear changes on conventional automatics is suppressed. Because of these control functions smooth gearshifts are possible and, due to the learning ability of some ECUs, the characteristics remain throughout the life of the system (Figure 9.13).

The ability to lock up the torque converter has been used for some time even on vehicles with more conventional automatic transmission. This gives better fuel economy, quietness and improved driveability. Lock-up is carried out using a hydraulic valve, which can be operated gradually to produce a smooth transition. The timing of lock-up is determined from ECU memory in terms of the vehicle speed and acceleration.

Def nition

DSG: Direct shift gearbox.

9.3.6 Direct shift gearbox

The direct shift gearbox (DSG) is an interesting development as it could be described as a manual gearbox that can change gear automatically. It can be operated by 'paddles' behind the steering wheel, a lever in the centre console or in a fully automatic mode. The gear train and synchronising components are similar to a normal manual change gearbox (Figure 9.14).

Key fact

A DSG can be operated by 'paddles' behind the steering wheel.

The direct shift gearbox is made of two transmission units that are independent of each other. Each transmission unit is constructed in the same way as a manual gearbox and is connected by a multiplate clutch. They are regulated, opened and closed by a mechatronics system. On the system outlined in this section:

- 1st, 3rd, 5th and reverse gears are selected via multiplate clutch 1.
- 2nd, 4th and 6th gears are selected via multiplate clutch 2.

Key fact

One transmission unit is always in gear and the other transmission unit has the next gear selected ready for the next change.

One transmission unit is always in gear and the other transmission unit has the next gear selected ready for the next change, but with its clutch still in the open position.

Torque is transmitted from the crankshaft to a dual-mass f ywheel. The splines of the f ywheel, on the input hub of the double clutch, transmit the torque to the drive plate of the multiplate clutch. This is joined to the outer plate carrier of clutch 1 with the main hub of the multiplate clutch. The outer plate carrier of clutch 2 is also positively joined to the main hub.

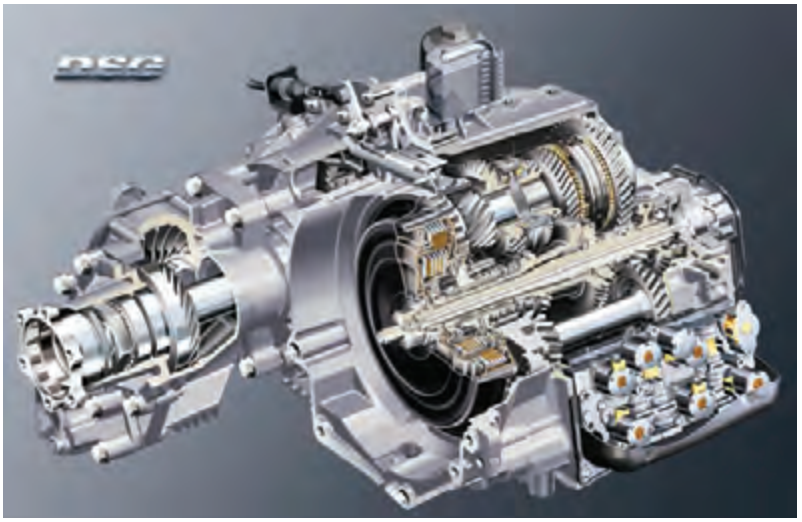


Figure 9.14 DSG (Source: Volkswagen Media)

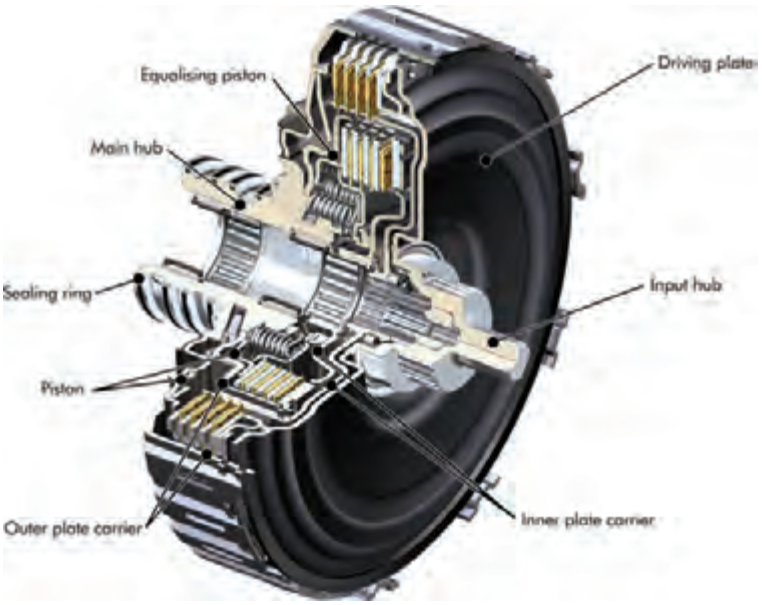


Figure 9.15 Multiplate twin clutch (Source: Volkswagen Media)



Figure 9.16 Ford twin-clutch transmission components (Source: Ford Media)

Torque is transmitted into the relevant clutch through the outer plate carrier. When the clutch closes, the torque is transmitted further into the inner plate carrier and then into the relevant gearbox input shaft. One multiplate clutch is always engaged (Figures 9.15 and 9.16).

9.4 Diagnostics – automatic transmission

9.4.1 Systematic testing

If the reported fault is that the kick down does not operate, proceed as follows:

1 Road test to conf rm the problem.
2 Is the problem worse when the engine is hot? Check the transmission f uid level. Has work been done to the engine?
3 If f uid level is correct, then you must investigate further. Work on the engine may have disturbed the kick down cable.
4 Check the adjustment/f tting of the kick down cable.
5 Adjust if incorrect.
6 Run and repeat road test.

Safety f rst

Note: You should always refer to the manufacturer's instructions appropriate to the equipment you are using.

9.4.2 Test equipment

Revcounter

A revcounter may be used during a stall test to check the operation of the torque converter and the automatic gearbox.

Pressure gauge

This is a standard type of gauge but with suitable adapters for connection to a gearbox. Figure 9.17 shows where various tests can be carried out on an automatic gearbox (Figure 9.18).

9.4.3 Test results

Some of the information you may have to get from other sources such as a data book or a workshop manual is listed in Table 9.3:

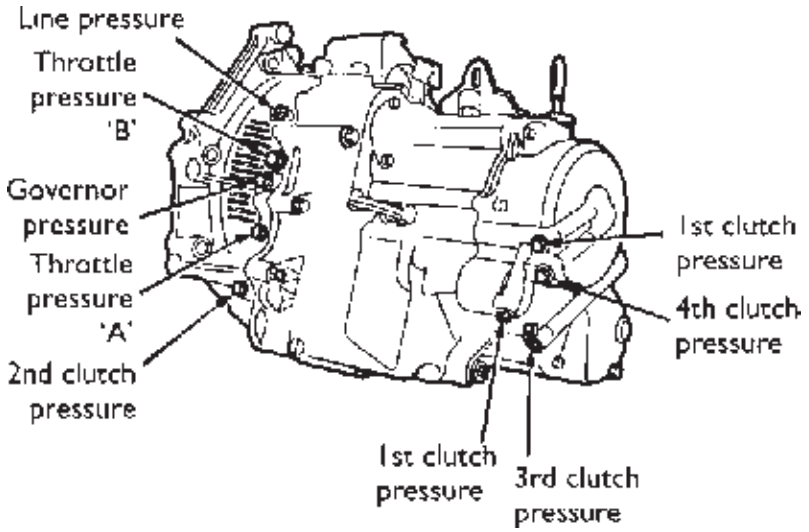


Figure 9.17 Transmission pressure testing points



Figure 9.18 Transmission system pressure test kit (Source: Snap-on)

Table 9.3 Tests and information required

Test carried out	Information required
Stall test	Highest revs expected and the recommended duration of the test
Kick down test	Rpm range in which the kick down should operate. For example, above a certain engine rpm, it may not be allowed to work

9.4.4 Automatic gearbox fault diagnosis table 1

Symptom	Possible faults	Suggested action
Slip, rough shifts, noisy operation or no drive	There are numerous faults that can cause these symptoms	Check the obvious such as fuid levels and condition Carry out a stall test Refer to a specialist if necessary

9.4.5 Automatic gearbox fault diagnosis table 2

Symptom	Possible cause
Fluid leaks	Gaskets or seals broken or worn Dip stick tube seal Oil cooler or pipes leaking
Discoloured and/or burnt smell to fluid	Low fluid level Slipping clutches and/or brake bands in the gearbox Fluid requires changing
Gear selection fault	Incorrect selector adjustment Low fluid level Incorrect kick down cable adjustment Load sensor fault (maybe vacuum pipe, etc.)
No kick down	Incorrect kick down cable adjustment Kick down cable broken Low fluid level
Engine will not start or start in gear	Inhibitor switch adjustment incorrect Faulty inhibitor switch Incorrect selector adjustment
Transmission slip, no drive or poor-quality shifts	Low fluid level Internal automatic gearbox faults often require the attention of a specialist

9.4.6 ECAT fault diagnosis table

Symptom	Possible fault
ECAT system reduced performance or not working	Communication link between engine and transmission ECUs open circuit Power supply/earth to ECU low or not present Transmission mechanical fault Gear selector switch open/short circuit Speed sensor inoperative Position switch fault Selection switch fault

9.4.7 Automatic transmission stall test

To assist with the diagnosis of automatic transmission faults, a stall test is often used. The duration of a stall test must not be more than approximately seven seconds. You should also allow at least two minutes before repeating the test. Refer to manufacturer's recommendations if necessary.

The function of this test is to determine the correct operation of the torque converter and that there is no transmission clutch slip. Proceed as follows:

1 Run engine up to normal operating temperature by road test if possible.
2 Check transmission fluid level and adjust if necessary.

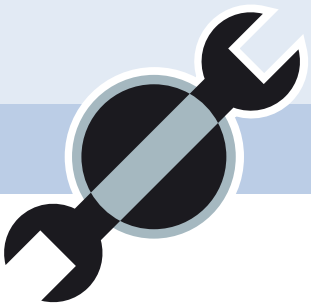


Safety first

Warning: If the precautions mentioned are not observed, the gearbox will overheat. Check manufacturer's data to make sure a stall test is an acceptable procedure.

3 Connect a revcounter to the engine.
4 Apply handbrake and chock the wheels.
5 Apply foot brake, select ‘D’ and fully press down the throttle for approximately seven seconds.
6 Note the highest rpm obtained (2500–2750 is a typically acceptable range).
7 Allow two minutes for cooling and then repeat the test in ‘2’ and ‘R’.

CHAPTER 10



Learning activities

10.1 Introduction

This section contains information, activities and ideas to help you learn more about automotive diagnostics. The best place to start is, of course, to read the content of the book. However, do remember when you are doing this to be active – in other words, make some notes, underline or highlight things and do not expect to understand something straight away – work at it!

I have created lots of useful online material that you can use. If you are at a school or college that is licensed to use my full blended eLearning package, you already have access to everything. However, if not at a licensed school or college, I have created a special area for you to use free of charge. Just go to: www.automotive-technology.co.uk and follow the links from there to f nd

- Multimedia (that includes some amazing animations)
- Practical activities
- Multiple-choice questions
- Short answer questions
- Glossaries
- Virtual toolboxes
- And more…

In this chapter, I have not created specif c assessment and learning activities for every subject; instead I have suggested types of activity and made a list of subjects or systems that can be the topic of the work. However, doing an assignment after each section of the book is a good way to check progress.

10.2 Knowledge check questions

To use these questions, you should f rst try to answer them without help, but if necessary, refer back to the content of the chapter. Use notes, lists and sketches as appropriate to answer them. It is not necessary to write pages and pages of text!

10.2.1 Chapter 1 Introduction

1 State the meaning of the terms ‘fault’ and ‘symptom’.
2 Explain how to reduce the risk of a short circuit when testing electrical systems.

Advanced Automotive Fault Diagnosis.
© 2012 Tom Denton. Published by Routledge. All rights reserved.

3 List the main headings that could be used for a standard report.
4 State the two main pieces of knowledge necessary to diagnose faults.
5 Describe the potential dangers of running an engine in an enclosed space without exhaust extraction.

10.2.2 Chapter 2 Diagnostic techniques

1 List the six-stage diagnostic process in your own words.
2 Explain how the six-stage process is used by giving a simple example.
3 State the length of a standard piece of string and explain why this is relevant to diagnostics!
4 Describe how to carry out tests for an electrical short circuit.
5 Explain using a sketch, what is meant by 'black box' faultf nding.

10.2.3 Chapter 3 Tools and equipment

1 Explain why a good multimeter has a high internal resistance.
2 List three advantages of using an oscilloscope for testing signals.
3 Describe how a scanner is connected to a vehicle and what information it can provide.
4 State what is meant by the term 'accuracy'.
5 List f ve tests carried out on a vehicle using a pressure gauge.

10.2.4 Chapter 4 Sensors, actuators and oscilloscope diagnostics

1 Explain the terms 'timebase', 'amplitude' and 'voltage scale'.
2 Make a sketch of ignition primary and ignition secondary waveforms. Label each part and state which aspects indicate that no faults are present.
3 Describe how to connect an oscilloscope to examine the signal supplied to a single-point (throttle body) injector.
4 State the typical output voltage (peak to peak) of an inductive crankshaft sensor at cranking, idle and 3000 rpm. Sketch the waveform to show the aspects that indicate engine speed and engine position.
5 Explain with the aid of a sketch why current limiting is used on the primary circuit of an ignition system.
6 Explain how a knock sensor operates and why it is used.
7 Describe how to test the operation of a Hall sensor using a multimeter.
8 List in a logical sequence how to diagnose a fault with one fuel injector on a V6 multipoint system.
9 Outline two methods of testing the operation of a sensor that uses a variable resistor (throttle pot or vane-type airf ow sensors for example).
10 Explain with the aid of a sketch, what is meant by 'duty cycle' in connection with an idle speed control valve.

10.2.5 Chapter 5 On-board diagnostics

1 State the main reasons why OBD was developed.
2 Explain what is meant by OBD monitors and list the most common.

3 Describe how the P codes are used to indicate faults.
4 Explain with the aid of a sketch, how the 'before and after cat' lambda sensor signals are used by the OBD system to monitor catalyst operation.
5 Explain what is meant by 'healing of the fault memory'.

10.2.6 Chapter 6 Engine systems

1 Describe how a VAT is used to check battery condition.
2 List in a logical sequence a series of tests that would determine why an engine, which is cranking over correctly, will not start.
3 Describe how the colour of smoke from a diesel engine can be used as an aid to fault diagnosis.
4 Make a block diagram to show the main components of an engine management system and how it can be considered as a series of inputs and outputs.
5 Describe how a cylinder leakage tester is used to check the condition of an engine.

10.2.7 Chapter 7 Chassis systems

1 Describe how to test the operation of an ABS wheel speed sensor.
2 List in a logical sequence a series of tests to determine the cause of steering pulling to one side when braking.
3 Describe a method of testing a damper (shock absorber).
4 Make a sketch to show three different types of tyre wear and state a possible cause for each.
5 Explain why it may be necessary to check the run-out on a brake disc (rotor) and describe how this is done.

10.2.8 Chapter 8 Electrical systems

1 Explain what is meant by 'controller area network (CAN)' and why it is used to connect ECUs or nodes together.
2 List in a logical sequence a series of steps to diagnose why a wiper motor operates on slow speed but not on fast speed.
3 Describe how to check that an on/off relay is operating correctly.
4 Describe how to test the output of a road speed sensor used as part of a cruise control system.
5 Make a sketch of a fuel gauge circuit and describe how to check it for correct operation.

10.2.9 Chapter 9 Transmission systems

1 Describe how to use a road test to diagnose a suspected CV joint fault.
2 Explain why a stall test may be used to diagnose automatic transmission faults.
3 List in a logical sequence a procedure for checking the operation of an electronically controlled automatic transmission.
4 Describe a procedure used to test for a slipping clutch.
5 Describe a series of steps that could be used to diagnose the source of a 'rumbling' noise from a transmission system.



Figure 10.1 Check engine!

10.3 Assignments

Using the information in this book, the resources on www.automotive-technology.co.uk and other Web sources, such as Wikipedia, there are lots of assignments you can carry out.

For example, referring to the subjects/systems listed below, you could

- Write a report to explain the operation and important features of *<insert subject or system here>.* Include images diagrams, tables, charts, bullets as needed. Remember that any report should have a beginning, a middle and an end – in other words, an introduction, the main bit, and a summary or conclusion.
- List the important aspects of *<insert subject or system here>.*
- Outline the diagnostic methods used to trace a fault in *<insert subject or system here>.*
- List the key types and functions of test equipment used to diagnose faults in *<insert subject or system here>.*
- State the reasons why and how a scanner is used to determine fault codes on *<insert subject or system here>*.
- Make a simple sketch to show how tests are carried out on *<insert subject or system here>*.

Your assignments could be 200, 500 or 1000 words long (or more) as appropriate, or as determined by your teacher, instructor or lecturer …. Note that Table 10.1 is pretty much the contents page of this book, but I have removed some parts and edited others to make it more appropriate for this section.

Table 10.1 List of assignment activities

(1) Introduction
 (a) Safe working practices

(2) Diagnostic techniques
 (a) Diagnostic process
 (b) Diagnostics on paper
 (c) Mechanical diagnostic techniques
 (d) Electrical diagnostic techniques
 (e) Fault codes
 (f) Systems
 (g) Data sources

(3) Tools and equipment
 (a) Basic equipment
 (b) Oscilloscopes
 (c) Scanners/fault code readers and analysers
 (d) Emission testing
 (e) Pressure testing

(4) Sensors, actuators and oscilloscope diagnostics
 (a) Sensors
 (b) Actuators
 (c) Engine waveforms
 (d) Communication networks

(*Continued*)

Table 10.1 (Continued)

(5) On-board diagnostics
- (a) History
- (b) Misf redetection
- (c) OBD2
- (d) EOBD
- (e) Monitors and readiness dgs
- (f) Future developments in diagnostic systems

(6) Engine systems
- (a) Engine operation
- (b) Fuel system
- (c) Ignition
- (d) Emissions
- (e) Fuel injection
- (f) Diesel injection
- (g) Engine management
- (h) Air supply and exhaust systems
- (i) Cooling
- (j) Lubrication
- (k) Batteries
- (l) Starting
- (m) Charging

(7) Chassis systems
- (a) Brakes
- (b) Antilock brakes
- (c) Traction control
- (d) Steering and tyres
- (e) Suspension
- (f) Active suspension

(8) Electrical systems
- (a) Electronic components and circuits
- (b) Multiplexing
- (c) Lighting
- (d) Auxiliaries
- (e) In car entertainment (ICE) security and communications
- (f) Body electrical systems
- (g) Instrumentation
- (h) Heating, ventilation and air conditioning (HVAC)
- (i) Cruise control
- (j) Air bags and belt tensioners

(9) Transmission systems
- (a) Manual transmission
- (b) Automatic transmission

10.4 Tips to help you learn

A good way to learn is to compare one method of doing something with another, for example:

1 What are the differences between OBD1 and OBD2?
2 How do the features of an oscilloscope compare to those of a multimeter?

Another good way to learn is to consider the advantages and disadvantages of things, for example:

1 What are the advantages and disadvantages of a simple test lamp?
2 What are the advantages of a battery discharge test compared to taking a voltage reading?

Also consider reasons why things have changed and developed in the way they have.

1 Why is almost everything now controlled by electronics?
2 Why is a modern scanner an essential tool?

Even thinking of these types of questions is a good way to learn, so I will leave the rest to you!

Safety f rst

Before starting any practical work you should have been trained or be supervised

10.5 Practical work

Remember, before starting any practical work, you should have been trained or be supervised. Also there are some key things you should always do:

1 Fit a vehicle body protection kit.
2 Prepare your standard tool kit.
3 Get the latest information and/or service manual.
4 Comply with personal and environmental safety practices associated with clothing; eye protection; hand tools; power equipment; proper ventilation; and the handling, storage, and disposal of chemicals/materials in accordance with all appropriate safety and environmental regulations.

10.6 Case studies

10.6.1 Introduction

This section outlines f ve short diagnostic case studies. The details are based on real-life situations posted on the International Automotive Technicians Network (IATN) website. I fully recommend this organisation, which is open to you if you are fully qualif ed or suitably experienced. Visit www.iatn.net for more information. Technicians can post information about a problem and ask questions. Others then make suggestions and, after the fault is f xed the original person states the actual fault and the associated repair.

I have edited and made the following case studies anonymous and added a few thoughts of my own. After reading each of these case studies in turn, see if you agree with me and also ask yourself three questions:

1 Was the process logical?
2 Were mistakes made?
3 Would you have done it differently?

This exercise is not meant to be critical of those who requested help. It is hard out there, particularly when customers are involved and are applying pressure – and often not wanting to pay much! However, a reminder to follow a logical process helps all of us. Figure 10.2 represents the recommended six-stage process.

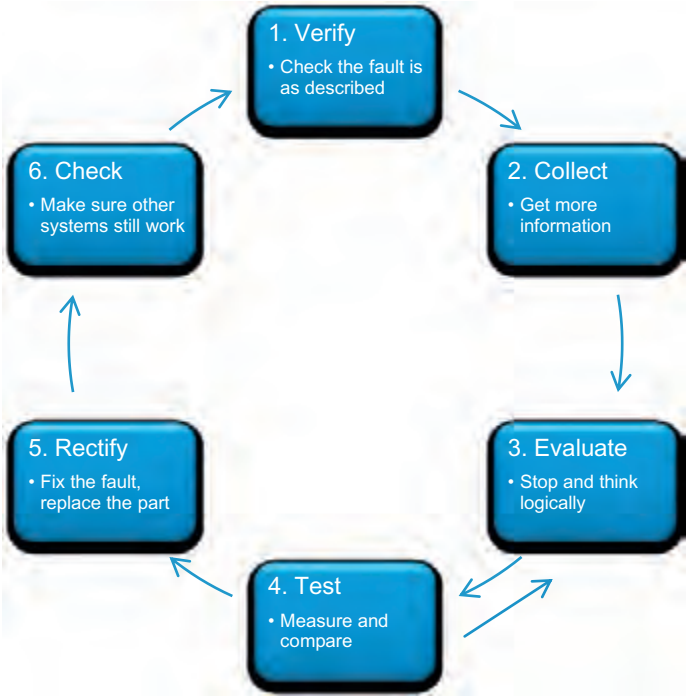


Figure 10.2 Six-stage diagnostic process

10.6.2 1997 Land Rover Discovery

- Mileage: 115 000 mi
- Engine: 4.0 L, 8 cyl, Gas/Petrol
- Trans: 4-speed Automatic
- Delivery: Fuel Injection
- Emissions: OBD-II Compliant
- Symptoms: Excessive Emissions, Hesitation, Misf re, Mil Lamp On
- Occurs: Hot

Related Repair History:

- Replaced items: fuel f lter, fuel pressure regulator, MAF sensor, fuel pump relay, IAC, cam sensor, all O_2 sensors, cat converters, coil pack, plugs, cleaned plenum, TPS

Computer Codes and Descriptions:

- 0152 – O_2 high volts bank 2 sensor1
- 0153 – O_2 high volts bank 1 sensor1
- 1191 – Fuel/air metering high

The car was brought to us with the above parts replaced by a do-it-yourself person. Upon road testing, starting f ne, but loss of power as it warms up. It has a high idle when warm. The scanner reported the O_2 sensors are not responding and are set at 4.5 V. We checked the new ones for correct connections and that they were the correct parts. All parts are OEM Land Rover. Continuity from the ECM to all O_2 sensors was OK.

I understand that the ECM varies the resistance to this type of O_2, thereby varying voltage from 1 to 5 V toggling rich to lean. Does the ECM on these older vehicles just default rich? I understand GEMS need to be reprogrammed if a TPS or other sensors are changed. Is that true for O_2 sensors? It seems to me there is an ECM problem.

Fault:

Intake manifold vacuum leaking. An updated intake gasket was installed. Upon removal we noted that all intake bolts were only f nger tight.

Tom's comment:

It's always a worry when a DIYer has been involved. Some are very good but in this case it appears that random parts were bolted on to try and f x the fault. I think this threw the technician in the repair shop off course at the beginning, which is why he started thinking ECM problems. However, he was thinking and that is the key, and did test like checking that the sensors were the correct ones.

The biggest clue to pick up on here I think, is that because the O_2 (lambda) sensors were giving an incorrect output on both banks (this is a V engine) the fault was most likely to be something in common with both sides.

Remember, a DTC from an O_2 sensor does not mean that the sensor is faulty; it simply means that the reading from the sensor is out of its normal range.

10.6.3 1999 Audi A4 Quattro

- Mileage: 83,000 mi
- Engine: 2.8 L, 6 cyl, Gas/Petrol
- Trans: 5-speed Automatic Transaxle (Electronic)
- Delivery: Fuel Injection

Technician's description:

This Audi has been to many workshops in the city and came to me with a fed-up customer! The problem is in the ABS system. There are no codes. It has the symptoms of the ABS coming on at 20 miles an hour and lower with moderate to heavy braking. I have resistance checked all the speed sensors at the ABS Module connector and came up with an average of 1.2 kohms. I have checked the voltages of all four sensors and they all produce between 0.2 to 0.6 AC volts with me spinning the wheel by hand with the car on the lift. I have checked the waveforms and they seem OK. Don't see any of them dropping out. Customer states that this problem happened a few years ago and he took it to a dealer where they found both rear wheel sensors were out of adjustment and the locking sleeve on the left rear sensor was missing. That cured the problem up until now.

My question is how do I check the adjustment of these sensors to the reluctor wheel? And are there any other items to check or methods to use to identify which sensor is causing this problem? I haven't been able to f nd any adjustment specs or procedures to set it to specs.

Fault:

First thing I did was to try and pull out the ABS Sensors in the R.F. R.R. and L.R. The L.F. Sensor and Axle were replaced by another shop that tried to f x the problem and then gave up. Because of rust I broke all three sensors getting them

out. I inspected all three pulse rings in the open holes and found the L.R. axle to have a broken one.

Tom's comment:

Most ABS problems do turn out to be sensor related and suspecting incorrect adjustment was the right thing to do. However, the broken pulse ring would have shown on a waveform. The diff culty is getting similar waveforms to compare because spinning the wheels by hand means they are likely to be checked at different speeds. Perhaps testing each sensor output at the ECU with the car driving at say 15 mph, and saving the waveform, would have shown the problem up. And the rust? Just unlucky for the customer in this case!

10.6.4 2002 Ford Ranger

- Mileage: 139 000 mi
- Engine: 3.0 L, 6 cyl, Gas/Petrol
- Trans: 5-speed Automatic (Electronic)
- Delivery: Fuel Injection
- Emissions: OBD-II Compliant
- Symptoms: Hesitation
- Occurs On: Acceleration

Related Repair History:

- Recent tune up, new plugs leads/wires and coil, DPFE (Differential Pressure Feedback of EGR) and control solenoid

Technician's description:

Vehicle came in with lack of power complaint. It seems to run f ne except a slight miss at idle, but you can barely tell. As soon as you try to accelerate it has no power. It does not fall on its face it just has no power. There are no fault codes in the computer. This vehicle is a commercial owned vehicle and is not well taken care of. All other sensor readings seem OK. The only one that I don't like is the TPS (throttle position), which reads 16% at idle, and the fuel trims seem really low. I am leaning towards cam sensor and syncro but I am not sure if anyone out there has come across this; it would greatly help me out if you could share what you know.

Fault:

It ended up being the transmission slipping just enough to feel like no power.

Tom's comment:

A recent tune up and new parts and no fault codes do suggest that the engine was OK but the symptoms contradicted this. A great example of a ref ected fault, i.e. a fault in one system that appears to show symptoms in another. We can also learn from this to always expect the unexpected!

10.6.5 2005 Volkswagen Jetta

- Mileage: 114 000 mi
- Engine: 2.0 L, 4 cyl, Gas/Petrol
- Trans: 6-speed Standard Transaxle (Electronic)
- Delivery: Fuel Injection
- Misc: P000? P0340

Technician's description:

This 2005 VW 2.0T Jetta has loud tapping noise while engine is running. The customer drove at 130–140 km/h for 4–5 hours long distant almost every week. When it came to our workshop, the oil level was below minimum level, but I don't think this would cause the engine damage. He was driving for about 4 hours on this occasion and when he slowed down the speed to 80–100 km/h he noticed that engine had the tapping noise. He continued to drove another hour and parked it at home. The next day he brought it to our repair shop (1st time customer for us). He does not have the car regularly serviced. He owned this car for two years. I am almost certain that engine top end is damaged; a cam lobe or lifter collapsing maybe, but I don't know why it happened.

Would driving 130–140 km/h for a long distance with minimum oil level do this? I would like to know the possible causes before we take the engine apart.

One more thing at one point the 'check engine light' came on. The DTCs were 'P000?' and 'P0340' (cam-position sensor).

Fault:

We used oil f ush before oil change for about 5 minutes; then replaced the oil and f lter. The loud tapping engine noise was still there for 5–6 minutes. We turned off engine, let it sit for 15 minutes, and when we restarted engine the noise disappeared after a short while. There was a very faint (knocking) noise on heavy acceleration. But it was so small that the customer will not hear it. We recommend to this customer that he should avoid heavy acceleration for a while and try to listen for any engine noise from now on because it may have damaged a bearing. And also we should replace the oil again after 4000–5000 km since it was using synthetic oil.

Tom's comment:

> *Having a car regularly serviced always saves money in the long term. I too suspect a cam lobe or lifter or similar. The technician did well here to think to try to oil f ush before stripping down the engine. I wonder if this customer appreciates how much money this saved him.*

10.6.6 2004 Honda Accord

- Mileage: 95 000 mi
- Engine: 3.0 L, 6 cyl, Gas/Petrol
- Trans: 5-speed Automatic Transaxle (Electronic)
- Delivery: Fuel Injection
- Affected: Air Flow
- Conditions: Not Cold

Related Repair History:

- Compressor and receiver drier replaced

Technician's description:

On this Honda Accord with automatic dual climate air conditioning, we replaced a compressor and drier because the passenger side air is cold, but the driver's side is lukewarm. The temperature f ap motors work like they are supposed to, that is, switching from hot to cold with no binding. I am thinking maybe the evaporator is partially plugged or the expansion valve is faulty. Everything else seems to be working f ne.

Fault:

Cleaned out evaporator and all OK, blocked on one side

Tom's comment:

The technician here missed out vital piece of information. If the passenger side AC was working OK, then the majority of the AC system such as the compressor and drier must also be OK. He did check the f aps which were a likely cause and got to the evaporator in the end but I wonder how much the new compressor cost the customer. Remember when evaluating evidence, it is always useful to know that something is NOT faulty because then you can use that fact to look further into the system. In this case, the concentration should have been only on what was common to just the driver side.

10.6.7 Summary

The main thing to learn from this section is that automotive diagnostics is never easy and that external factors can have an undue inf uence on our thinking processes if we do not take care. Always believe your test results but also consider the wider possibilities of what may cause them. Overall, the real secret is logic.

10.7 Software

I have created a simulation program that can be used to help you learn more about engine management systems and how to diagnose faults. It is a great teaching aid and covers some complex topics in an easy-to-understand way. It is even possible to set faults in the system and then, using built-in test equipment, carry out diagnostic tests.

You can set or control the operating inputs to the system. For engine management control, these are engine speed, engine load, temperature and so on. The system will then react and control the outputs in just the same way as a real vehicle. Be warned the unregistered version runs out of fuel!

Web

Shareware and other great resources are available from: www.automotive-technology.co.uk

10.8 Summary

Modern motor vehicles are highly sophisticated machines that incorporate the latest developments in electrical, electronics, software and mechanical engineering. They are a marvel of modern engineering practice and truly show how all these technologies can be integrated and harmonised for maximum benef t to the end user. It is clear that this level of technology produces the safest, quietest and most eff cient road vehicles we have ever known.

However, the disadvantage of this level of sophistication becomes apparent when something goes wrong. Clearly, the more sophisticated the device, the more diff cult it will be to repair, or understand in order to repair. It is often the case that it may be perceived that no faults can be found or f xed without specialised manufacturer equipment which is only available at dealers. This is not the case. The fundamental principles of diagnostics in conjunction with an applied, logical thought process are the most powerful tools that you have. Any specialist equipment will still only be as good as the person using it.

Modern vehicle systems are certainly sophisticated, but the fundamental principles apply. An ECU is only monitoring voltages from its sensors. These voltages are the inputs to the ECU; its outputs are voltages and currents which drive actuators (injector, idle speed control valves, etc.), they are all the same and applied logic can f x most problems. Engines and chassis are also complicated subsystems of the vehicle, but in all cases the laws of physics apply, and all engines do the same thing in more or less the same way. They are just energy converters. The basic principles are still valid; for example, the ignition still needs to be advanced under cruise conditions when the mixture is weaker, whether this is done mechanically or electronically. Likewise, any electrical circuit not conducting a current – is broken – somewhere.

Def nition

Laws of physics: "a cannae change them".

There are always a few simple rules to follow:

- Do not overlook the obvious.
- Look for simple solutions f rst.
- Always get as much information as possible up front.
- Never assume anything … check it yourself.
- Be logical when diagnosing faults.
- Most of all, have conf dence in your ability.

Follow these rules, never be afraid to ask for help and learn from the experience. In this way, you will build up a portfolio of useful experience and knowledge that will help develop your career as a diagnostic expert. There is nothing that quite beats the feeling of solving a problem, especially if you know that it has puzzled other people before you – to the point that they have given up.

One f nal point, see the red thing in the middle of the following picture? Do not forget to check the obvious, no matter how complex a vehicle may appear to be (Figure 10.3)!

Well, that's it, if you have arrived here, after having read all the book, done all the assignments, completed all the practical tasks, used the website: www.automotive-technology.co.uk resources and can remember everything, then well done.

Or did you just start reading the book from the back?



Figure 10.3 Even the BMW M3 engine needs oil

Glossary of abbreviations and acronyms



OBD2/SAE terminology

ABS *antilock brake system*
A/C *air conditioning*
AC *air cleaner*
AIR *secondary air injection*
A/T *automatic transmission or transaxle*
B+ *battery positive voltage*
BARO *barometric pressure*
CAC *charge air cooler*
CFI *continuous fuel injection*
CKP *crankshaft position sensor*
CKP REF *crankshaft reference*
CL *closed loop*
CMP *camshaft position sensor*
CMP REF *camshaft reference*
CO *carbon monoxide*
CO_2 *carbon dioxide*
CPP *clutch pedal position*
CTOX *continuous trap oxidiser*
CTP *closed throttle position*
DEPS *digital engine position sensor*
DFCO *decel fuel cut-off mode*
DFI *direct fuel injection*
DLC *data link connector*
DPF *diesel particulate f lter*
DTC *diagnostic trouble code*
DTM *diagnostic test mode*
EBCM *electronic brake control module*
EBTCM *electronic brake traction control module*
EC *engine control*
ECL *engine coolant level*

ECM *engine control module*
ECT *engine coolant temperature*
EEPROM *electrically erasable programmable read only memory*
EFE *early fuel evaporation*
EGR *exhaust gas recirculation*
EGRT *EGR temperature*
EI *electronic ignition*
EM *engine modif cation*
EPROM *erasable programmable read only memory*
ESC *electronic stability control*
EVAP *evaporative emission system*
FC *fan control*
FEEPROM *f ash electrically erasable programmable read only memory*
FF *f exible fuel*
FP *fuel pump*
FPROM *f ash erasable programmable read only memory*
FT *fuel trim*
FTP *federal test procedure*
GCM *governor control module*
GEN *generator*
GND *ground*
HC *hydrocarbon*
H_2O *water*
HO2S *heated oxygen sensor*
HO2S1 *upstream heated oxygen sensor*
HO2S2 *up or downstream heated oxygen sensor*
HO2S3 *downstream heated oxygen sensor*
HVAC *heating ventilation and air conditioning system*
HVS *high-voltage switch*
IA *intake air*
IAC *idle air control*
IAT *intake air temperature*
IC *ignition control circuit*
ICM *ignition control module*
IFI *indirect fuel injection*
IFS *inertia fuel shutoff*
I/M *inspection/maintenance*
IPC *instrument panel cluster*
ISC *idle speed control*
KOEC *key on, engine cranking*
KOEO *key on, engine off*

KOER *key on, engine running*
KS *knock sensor*
KSM *knock sensor module*
LTFT *long-term fuel trim*
MAF *mass airf ow sensor*
MAP *manifold absolute pressure sensor*
MC *mixture control*
MDP *manifold differential pressure*
MFI *multiport fuel injection*
MIL *malfunction indicator lamp*
MPH *miles per hour*
MST *manifold surface temperature*
MVZ *manifold vacuum zone*
NVRAM *non-volatile random access memory*
NOX *oxides of nitrogen*
OBD *on-board diagnostics*
OBD I *on-board diagnostics generation one*
OBD II *on-board diagnostics, second generation*
OC *oxidation catalyst*
ODM *output device monitor*
OL *open loop*
O2S *oxygen sensor*
OSC *oxygen sensor storage*
PAIR *pulsed secondary air injection*
PCM *powertrain control module*
PCV *positive crankcase ventilation*
PNP *park/neutral switch*
PROM *program read only memory*
PSA *pressure switch assembly*
PSP *power steering pressure*
PTOX *periodic trap oxidiser*
RAM *random access memory*
RM *relay module*
ROM *read only memory*
RPM *revolutions per minute*
SAP *accelerator pedal*
SC *supercharger*
SCB *supercharger bypass*
SDM *sensing diagnostic mode*
SFI *sequential fuel injection*
SRI *service reminder indicator*

SRT *system readiness test*
STFT *short-term fuel trim*
TB *throttle body*
TBI *throttle body injection*
TC *turbocharger*
TCC *torque converter clutch*
TCM *transmission or transaxle control module*
TFP *throttle f uid pressure*
TP *throttle position*
TPS *throttle position sensor*
TVV *thermal vacuum valve*
TWC *three-way catalyst*
TWC+OC *three-way+oxidation catalytic converter*
VAF *volume airf ow*
VCM *vehicle control module*
VR *voltage regulator*
VS *vehicle sensor*
VSS *vehicle speed sensor*
WU-TWC *warm up three-way catalytic converter*
WOT *wide open throttle*

OEM and other terminology

A *amps*
AAV *anti-afterburn valve (Mazda)*
ABS *antilock brake system*
ABSV *air bypass solenoid valve (Mazda)*
A/C *air conditioning*
AC *alternating current*
ACTS *air charge temperature sensor (Ford)*
AERA *Automotive Engine Rebuilders Association*
A/F *air/fuel ratio*
AFM *airf ow meter*
AFS *airf ow sensor (Mitsubishi)*
AIR *Air Injection Reaction (GM)*
AIS *Air Injection System (Chrysler)*
AIS *automatic idle speed motor (Chrysler)*
ALCL *assembly line communications link (GM)*
ALDL *assembly line data link (GM)*
API *American Petroleum Institute*
APS *absolute pressure sensor (GM)*

APS *atmospheric pressure sensor (Mazda)*
ASD *automatic shutdown relay (Chrysler)*
ASDM *airbag system diagnostic module (Chrysler)*
ASE *Automotive Service Excellence*
A/T *automatic transmission*
ATC *after top centre*
ATDC *after top dead centre*
ATF *automatic transmission f uid*
ATMC *Automotive Training Managers Council*
ATS *air temperature sensor (Chrysler)*
AWD *all-wheel drive*
BARO *barometric pressure sensor (GM)*
BAT *battery*
BCM *body control module (GM)*
BHP *brake horsepower*
BID *Breakerless Inductive Discharge (AMC)*
BMAP *barometric/manifold absolute pressure sensor (Ford)*
BP *backpressure sensor (Ford)*
BPS *barometric pressure sensor (Ford & Nissan)*
BPT *backpressure transducer*
BTC *before top centre*
BTDC *before top dead centre*
Btu *British thermal units*
C *Celsius*
C3 *Computer Command Control system (GM)*
C3I *Computer Controlled Coil Ignition (GM)*
C4 *Computer Controlled Catalytic Converter system (GM)*
CAAT *Council of Advanced Automotive Trainers*
CAFE *corporate average fuel economy*
CALPAK *calibration pack*
CANP *canister purge solenoid valve (Ford)*
CARB *California Air Resources Board*
CAS *Clean Air System (Chrysler)*
CAS *crank angle sensor*
CC *catalytic converter*
CC *cubic centimetres*
CCC *Computer Command Control system (GM)*
CCD *computer controlled dwell (Ford)*
CCEI *Coolant Controlled Idle Enrichment (Chrysler)*
CCEV *Coolant Controlled Engine Vacuum Switch (Chrysler)*
CCOT *clutch cycling orif ce tube*

CCP *controlled canister purge (GM)*
CCV *canister control valve*
CDI *Capacitor Discharge Ignition (AMC)*
CEAB *cold engine air bleed*
CEC *Crankcase Emission Control System (Honda)*
CECU *central electronic control unit (Nissan)*
CER *cold enrichment rod (Ford)*
CESS *cold engine sensor switch*
CFC *chlorof uorocarbons*
CFI *Cross Fire Injection (Chevrolet)*
cfm *cubic feet per minute*
CID *cubic inch displacement*
CID *cylinder identif cation sensor (Ford)*
CIS *Continuous Injection System (Bosch)*
CMP *camshaft position sensor (GM)*
COP *coil on plug ignition*
CP *canister purge (GM)*
CP *crankshaft position sensor (Ford)*
CPI *Central Port Injection (GM)*
CPU *central processing unit*
CSC *Coolant Spark Control (Ford)*
CSSA *Cold Start Spark Advance (Ford)*
CSSH *Cold Start Spark Hold (Ford)*
CTAV *Cold Temperature Actuated Vacuum (Ford)*
CTO *Coolant Temperature Override Switch (AMC)*
CTS *charge temperature switch (Chrysler)*
CTS *coolant temperature sensor (GM)*
CTVS *choke thermal vacuum switch*
CVCC *Compound Vortex Controlled Combustion system (Honda)*
CVR *control vacuum regulator (Ford)*
dB *decibels*
DC *direct current*
DEFI *Digital Electronic Fuel Injection (Cadillac)*
DERM *diagnostic energy reserve module (GM)*
DFS *deceleration fuel shutoff (Ford)*
DIS *Direct Ignition System (GM)*
DIS *Distributorless Ignition System (Ford)*
DLC *data link connector (GM)*
DOHC *dual overhead cams*
DOT *Department of Transportation*
DPF *diesel particulate f lter*

DRBII *Diagnostic Readout Box (Chrysler)*
DRCV *distributor retard control valve*
DSSA *Dual Signal Spark Advance (Ford)*
DVDSV *differential vacuum delay and separator valve*
DVDV *distributor vacuum delay valve*
DVOM *digital volt ohm meter*
EACV *electronic air control valve (Honda)*
EBCM *electronic brake control module (GM)*
EBM *electronic body module (GM)*
ECA *electronic control assembly*
ECCS *Electronic Concentrated Control System (Nissan)*
ECM *electronic control module (GM)*
ECS *Evaporation Control System (Chrysler)*
ECT *engine coolant temperature (Ford & GM)*
ECU *electronic control unit (Ford, Honda & Toyota)*
EDIS *Electronic Distributorless Ignition System (Ford)*
EEC *Electronic Engine Control (Ford)*
EEC *Evaporative Emission Controls (Ford)*
EECS *Evaporative Emissions Control system (GM)*
EEPROM *electronically erasable programmable read only memory chip*
EFC *electronic feedback carburettor (Chrysler)*
EFC *electronic fuel control*
EFCA *electronic fuel control assembly (Ford)*
EFE *Early Fuel Evaporation system (GM)*
EFI *electronic fuel injection*
EGO *exhaust gas oxygen sensor (Ford)*
EGRPS *EGR valve position sensor (Mazda)*
EGR-SV *EGR solenoid valve (Mazda)*
EGRTV *EGR thermo valve (Chrysler)*
EI *electronic ignition (GM)*
ELB *Electronic Lean Burn (Chrysler)*
EMI *electromagnetic interference*
EOS *exhaust oxygen sensor*
EPA *Environmental Protection Agency*
EPOS *EGR valve position sensor (Ford)*
EPROM *erasable programmable read only memory chip*
ESA *Electronic Spark Advance (Chrysler)*
ESC *Electronic Spark Control (GM)*
ESS *Electronic Spark Selection (Cadillac)*
EST *Electronic Spark Timing (GM)*
EVP *EGR valve position sensor (Ford)*

EVRV *electronic vacuum regulator valve for EGR (GM)*
F *Fahrenheit*
FBC *feedback carburettor system (Ford & Mitsubishi)*
FBCA *feedback carburettor actuator (Ford)*
FCA *fuel control assembly (Chrysler)*
FCS *fuel control solenoid (Ford)*
FDC *fuel deceleration valve (Ford)*
FI *fuel injection*
FLS *f uid level sensor (GM)*
FMVSS *Federal Motor Vehicle Safety Standards*
ft. lb. *foot pound*
FUBAR *Fracked Up Beyond All Repair*
FWD *front-wheel drive*
gal *gallon*
GND *ground*
GPM *grams per mile*
HAIS *Heated Air Intake System (Chrysler)*
HEGO *heated exhaust gas oxygen sensor*
HEI *High Energy Ignition (GM)*
Hg *mercury*
hp *horsepower*
IAC *idle air control (GM)*
IAT *inlet air temperature sensor (Ford)*
IATS *intake air temperature sensor (Mazda)*
IC *integrated circuit*
ICS *idle control solenoid (GM)*
ID *inside diameter*
IGN *ignition*
IIIBDFI *If it isn't broke don't f x it*
IM240 *inspection/maintenance 240 program*
IMI *Institute of the Motor Industry*
I/P *instrument panel*
ISC *idle speed control (GM)*
ISO *International Standards Organization*
ITCS *Ignition Timing Control System (Honda)*
ITS *idle tracking switch (Ford)*
JAS *Jet Air System (Mitsubishi)*
kHz *kilohertz*
KISS *Keep It Simple Stupid!*
km *kilometres*
kPa *kilopascals*

KS *knock sensor*
kV *kilovolts*
L *litres*
lb. ft. *pound feet*
LCD *liquid crystal display*
LED *light-emitting diode*
MACS *Mobile Air Conditioning Society*
MAF *mass airf ow sensor*
MAMA *Midwest Automotive Media Association*
MAP *manifold absolute pressure*
MAP *Motorist Assurance Program*
MAT *manifold air temperature*
MCS *mixture control solenoid (GM)*
MCT *manifold charge temperature (Ford)*
MCU *Microprocessor Controlled Unit (Ford)*
MFI *multiport fuel injection*
MIL *malfunction indicator lamp*
MISAR *Microprocessed Sensing and Automatic Regulation (GM)*
mm *millimetres*
MPFI *multi point fuel injection*
MPG *miles per gallon*
MPH *miles per hour*
MPI *multi-port injection*
ms *millisecond*
MSDS *material safety data sheet*
mV *millivolts*
NACAT *National Association of College Automotive Teachers*
NATEF *National Automotive Technician's Education Foundation*
NHTSA *National Highway Traff c Safety Administration*
Nm *Newton metres*
OBD *on-board diagnostics*
OC *oxidation converter (GM)*
OD *outside diameter*
OE *original equipment*
OEM *original equipment manufacture*
OHC *overhead cam*
ORC *oxidation reduction catalyst (GM)*
OS *oxygen sensor*
OSAC *Orif ce Spark Advance Control (Chrysler)*
P/B *power brakes*
P/N *part number*

PA *pressure air (Honda)*
PAFS *Pulse Air Feeder System (Chrysler)*
PAIR *Pulsed Secondary Air Injection system (GM)*
PCM *powertrain control module (supersedes ECM)*
PECV *power enrichment control valve*
PERA *Production Engine Rebuilders Association*
PFI *port fuel injection (GM)*
PGM-FI *Programmed Gas Management Fuel Injection (Honda)*
PIP *prof le ignition pickup (Ford)*
PPM *parts per million*
PROM *program read only memory computer chip*
PS *power steering*
PSI *pounds per square inch*
pt. *pint*
PVA *ported vacuum advance*
PVS *ported vacuum switch*
QS9000 *Quality assurance standard for OEM part suppliers*
Qt. *quart*
RABS *Rear wheel Antilock Brake System (Ford)*
RFI *radio frequency interference*
RPM *revolutions per minute*
RPO *regular production option*
RWAL *Rear Wheel Antilock brake system (GM)*
RWD *rear-wheel drive*
SAE *Society of Automotive Engineers*
SAVM *spark advance vacuum modulator*
SCC *Spark Control Computer (Chrysler)*
SDI *Saab Direct Ignition*
SES *service engine soon indicator (GM)*
SFI *Sequential Fuel Injection (GM)*
SIR *Supplemental Inf atable Restraint (air bag)*
SMPI *Sequential Multiport Fuel Injection (Chrysler)*
SOHC *single overhead cam*
SPOUT *Spark Output signal (Ford)*
SRDV *spark retard delay valve*
SRS *Supplemental Restraint System (air bag)*
SS *speed sensor (Honda)*
SSI *Solid State Ignition (Ford)*
STS *Service Technicians Society*
TA *temperature air (Honda)*
TABPV *throttle air bypass valve (Ford)*

TAC *thermostatic air cleaner (GM)*
TACH *tachometer*
TAD *Thermactor air diverter valve (Ford)*
TAV *temperature actuated vacuum*
TBI *throttle body injection*
TCC *torque converter clutch (GM)*
TCCS *Toyota Computer Controlled System*
TCS *Transmission Controlled Spark (GM)*
TDC *top dead centre*
TIC *thermal ignition control (Chrysler)*
TIV *Thermactor idle vacuum valve (Ford)*
TKS *throttle kicker solenoid (Ford)*
TP *throttle position sensor (Ford)*
TPI *Tuned Port Injection (Chevrolet)*
TPMS *Tyre Pressure Monitor System*
TPP *throttle position potentiometer*
TPS *throttle position sensor*
TPT *throttle position transducer (Chrysler)*
TRS *Transmission Regulated Spark (Ford)*
TSP *throttle solenoid positioner (Ford)*
TV *throttle valve*
TVS *thermal vacuum switch*
TVS *thermal vacuum switch (GM)*
TVV *thermal vacuum valve (GM)*
V *volts*
VAC *volts alternating current*
VAF *vane airf ow sensor*
VCC *viscous converter clutch (GM)*
VDC *volts direct current*
VDV *vacuum delay valve*
VIN *vehicle identif cation number*
VSM *vehicle security module*
VSS *vehicle speed sensor*
WOT *wide open throttle*
WOT *wide open throttle switch (GM)*
WSS *wheel speed sensor*

Index



A

ABS 264
- advantages 265
- bleeding 271
- calculations 267
- closed loop block diagram 267
- components 266
- diagnosis chart 269
- diagnostics 269
- electronic control unit 268
- fault diagnosis table 270
- general system description 266
- hydraulic modulator 268
- requirements 265–266
- systematic testing procedure 269
- wheel speed sensors 266

Accurate measurement process 45
Actuators 93–106
- diagnostic methods 95
- motorised 94–98
- motors 94
- rotary idle speed control valve 96–97
- solenoid 94, 98–106
 - carbon canister valve 106
 - common rail diesel injector 103, 104
 - exhaust gas recirculation valve 105
 - idle speed control
 - valve 103–104, 105
 - Multi-point injector 102–103
 - single-point injector 100–101
- stepper motors 97–98, 99
- testing 94
- thermal 106
- window lift and wiper motors 96

Airbags 371
- activation procedure 375–377
- circuit 372
- components 372
- deactivation procedure 375–377
- diagnostics 375
- reactivation procedure 377

Air conditioning 361–362
- fault diagnosis table 365, 366
- operation 363

Air supply system 224–225
- fault diagnosis 225–226
- systematic testing 225

Alternator waveform 111–112
Analogue MAP sensor 90
Analogue meters 22
Anti-roll bar 289–290
Assignments 402–403
Automatic temperature control 363
Automatic transmission 388
- diagnosis 395–397
- stall test 397–398

Auto Tap OBD Scanner 52–53

B

Batteries 235
- charging 238–239
- components 236
- diagnostics 237
- faults 239–240
- high-quality 235
- lead-acid 235
- maintenance-free 238
- rating 236–237
- safety 235
- servicing 237
- smart chargers 239
- testing 240
- voltages 241

Belt tensioners 371
Black box technique 25–26
Body electrical systems 344
- circuit systematic testing 350–351
- diagnostics 348–350

Bosch ESI tronic 38–39
Bosch KTS diagnostic equipment 53–55
Brake lights 329–340
Brakes 257
- ABS 264 see also ABS
- adjustments 260
- antilock brakes 264
- brake f uid tester 261
- brake roller test 261
- checking for disc run out with dial gauge 262
- diagnostics 261
- dial gauge 262
- disc system 259
- drum system 259
- fault diagnosis 263–264
- hydraulic braking 258
- hydraulic faults 264
- master cylinder operation 258
- servo-assisted 260
- systematic testing 261
- test equipment 261
- traction control 271

C

Camber 277
Camshaft drives 153

CAN 113–116, 307
data signal 310–311
disconnecting nodes 310
DLC socket 114
KTS 200 kit 316
message format 310
pin data link connector 315
signals 313, 314–315
spark ignition engine cranking amps 114
test box 316
Carburation 161–165
f oat and needle valve 163
main jet in fuel feed to venturi 163
stages 164–165
throttle butterf y 162
Volkswagen Jetta 2005 407–408
Castor 277–278
Catalytic converter diesel 200–201
Catalytic converters 186–187, 222–224
components 223
operation 223
Charging 249
alternator components 250
alternator internal circuit 252
basic principles 251
brush box 254
circuits 253–256
diagnosis chart 255
diagnostics 256
example circuits 254
fault diagnosis table 256
rectif cation of AC to DC 251–252
regulation of output voltage 253
testing procedure 256
voltage regulator 254
Chassis systems 257
Clutch 379–380
faults diagnosis table 387
Communication networks 113–118
Constantly variable transmission 390–391
Cooling 226
air-cooled system 226
fault diagnosis 230
sealed systems 227–228
semi-sealed systems 227–228
systematic testing 228–229
test equipment 229
test results 229
water-cooled system 226–227
Crank speed f uctuation 138
Crankcase ventilation engine breather systems 233
Cruise control 367
components 369
diagnostics 369–371
system description 368–369
systematic testing 369
Cylinder pressure sensing 140

D

Dampers 290
types 292
Data sources 36–41
Autodata 38
Bosch ESItronic 38–39
example 37
fuel injection testing example 40
Delphi MagneRide 297–299
Diagnosis 1
what is needed to f nd faults 1
Diagnostic data link corrector 51
logic 9
where to stop 9
Diagnostic process 10–16
art of diagnostics 11–12
cause, concern, correction 12–13
root cause analysis 13–15
six-stage 10–11
Diagnostic techniques 9–41
information 9
Diagnostics on paper 16–17
examples 16
valid reading or measurement 17
Diesel engine smoke 202–204
black 203
blue 203
grey 203
white 203
Diesel exhaust emission 200
f lters 201
Diesel glow plugs 110–111
Diesel injection 195–205
common rail systems 198–199
diagnostics 201–205
diesel systems 204–205
electronic control 197–198
fault diagnosis table 202
gas analyser 201
generic diagnostic process 205
glow plug circuit 204
injector tester 201
smoke meter 201
test equipment 201–202
Differential 384
Digital circuits 304
Digital instrumentation 352–353
Digital MAP sensor 90
Direct shift gearbox 393–394
Displays 355
Door locking circuit 346–347
Driveshafts 381
fault diagnosis table 387
Driving cycles 145–147
Europe 145–146
United States 146–147
Dynamic position sensors 92–93

E

Electric horns 330–331
Electric mirrors 345
Electric seat adjustment 344–345
Electric sunroof operation 345–346
Electric window operation 347–348
Electrical diagnostic techniques 22–31
analogue meters 22
back probing connectors 30–31
black box technique 25–26

colour codes 28–29, 30
DIN Terminal numbers 29
faultf nding by luck or logic 27–28
f ight recorder tests 26–27
Ford system codes 30
generic procedure 23
on and off load tests 25
sensor to ECU method 26
terminal numbers 28–29
test lights 22
testing for short circuits to earth 24
volt drop testing 24
Electrical systems 301
auxiliary
diagnostics 332, 333
fault diagnosis table 334
testing procedure 332, 333
CAN 307
circuit symbols 302
component testing 305
digital circuits 304
FlexRay 312
integrated circuits 303–304
LIN 311
multiplexing 306
transistor testing 306
Emission limits 60–61
European 62
United States 63
Emission sources 185
Emission testing 59–62
exhaust analyser 60
exhaust gas measurement 59–60
exhaust gas measuring components 61
Emissions 185–187
adjustment and emissions data example 190
diagnostics 187–189
fault diagnosis table 189
testing procedure 187–188
systems diagnosis chart 188
Emissions control legislation
history of 120–122
Engine analysers 55–59
connections 59
typical waveforms 59
Engine cooling fan motors 331–332
Engine management 168, 205–213
circuit diagram 219, 221
closed-top lambda control 206
component testing data 219
components 208
diagnosis charts 219
diagnostics 213
fault diagnosis table 215–217
faultf nding chart 214, 220
gasoline direct injection 212–213
ignition timing, dwell and lambda maps 209
operation 206–212
roller cell pump 210–211
testing data 222
testing procedure 213
Engine noises 20–21
sources 21
Engine operation 151–156
camshaft drives 153
cylinder layouts 153
timing belt data 154
valve and ignition timing 155–156
valve mechanisms 153–155
valve timing diagrams 155
Engine systems 151–256
diagnostics 156–160
diagnostic gauges 157
systemic testing example 156
tables 158–160
test equipment 156–157
engine management 168
Engine waveforms 106–113
altenator ripple voltage 112
altenator waveform 111–112
diesel glow plugs 110–111
ignition primary 106–108
ignition secondary 108–110
relative compression petrol 112–113
Environmental health
vehicle emissions, and 119–120
EOBD 142–144
Epicyclic gearbox operation 389–390
Equipment 43–65
basic 43
Exhaust analyser 60
Exhaust emissions 185
Exhaust gas measurement 59–60
Exhaust gas recirculation 186
Exhaust gas recirculation monitor 132–133
Exhaust pressure analysis 140
Exhaust system 219–222
fault diagnosis 225–226
noise reduction methods 223
systematic testing 225

F

Fault code readers and analysers 50–59
Fault codes 31–34
clearing 33–34
examples 32
fast and slow 31–32
OBD2 DTCs 32–33
Fault diagnosis with KTS 56–58
Final drive 384
fault diagnosis table 387
FlexRay 116–117, 312
backbone 313
signal 117
Flight recorder tests 26–27
Four-stroke cycle 151–152
Four wheel alignment 281
Four-wheel drive systems 384
Fuel injection 189–194
air fuel ratio 189
components 191–193
diagnostics 165–167, 194–195
fuel mixture calculation 193–194
system diagnosis chart 196
testing procedure 194

Fuel pump testing 217–218
Fuel pressure 89
Fuel system 160–167
 carburation 161–165
 exhaust gas analyser 166
 fuel fault diagnosis 167
 systematic testing example 165
 test equipment 166

G
Gasoline direct injection 212–213
 atomization 213
Gauges 351–352
Gearbox
 direct shift 393–394
 manual 380–381, 382, 383
Glossary 411–421
Glow plug circuit 204

H
Hall effect distributor 170–171
Hall effect sensors 80–82
 Hall sensor data 82
 Hall output waveform 81
Hazard lights 329, 330
Headlight wipers and washers 328–329
Heating 359
 blower motors 360
 electronic control 360
 fault diagnosis table 367
 water-cooled engine 359–360
Horns 330–331

I
Ignition 168–184
 advanced angle (timing) 168–169
 basics 168
 closed-loop 171–172
 components 181–182
 current-limiting 171–172
 diagnostics 179–184
 direct 176–177
 DIS diagnostics 183
 distributorless 175–176
 electronic 169–170
 electronic spark advance 172–175
 fault diagnosis table 181
 Hall effect distributor 170–171
 inductive distributor 171
 programmed 172–175
 testing procedure 179–180
 timing light 182
In-car entertainment 336
 circuit 337
 diagnostics 339, 340–342
 interference suppression 342–344
Indicators 329, 330
Inductive distributor 171
Inertia starters 243
Injector testing 218–219
Instrumentation 351
Instruments
 black box technique 356
 diagnostics 356–358
Integrated circuits 303–304

K
Knock sensor 83–84
Knowledge check questions 399–401

L
Learning activities 399–410
 practical work 404
 software 409
Lighting 316–321
 adaptive lighting using LEDs 321
 asymmetric dip beam pattern 325
 circuits 317–318
 complete circuit 320
 diagnostics 321, 322
 external lights 316–317
 fault diagnosis table 323
 features 318
 gas discharge 318–319
 headlamp alignment 324
 headlights 324
 LED 319, 321
 simplif ed circuit 319
 testing procedure 321
 Xenon 321
LIN 116, 311
 waveform 116
Logic 9
Logic probe 47
Low fuel warning 353
Lubrication 230
 diagnostics 233
 fault diagnosis 234–235
 oil pressure test gauge 234
 systematic testing 233
 test equipment 234
 vacuum gauge 234

M
Manifold absolute pressure 89
Manual gearbox 380–381, 382, 383
Mechanical diagnostic techniques 17–22
 check obvious f rst 17
 engine noises 20–21
 noise conditions 18
 noise, vibration and harshness 17–18
 road test 19–20
 vibration conditions 19
Misf re detection 135–140
 crank speed f uctuation 138
 cylinder pressure sensing 140
 exhaust pressure analysis 140
 ionising current monitoring 138–139
 misf re monitor 135–138
Mobile communications 339
 diagnostics 339–342

Multimeters 45–47
functions 46
meter resistance 46–47
Multiplexing 306
diagnostics 312

N

Noise conditions 18
Noise, vibration and harshness 17–18

O

Oil f lters 231–232
Oil pumps 232–233
Oil quality sensors 90–91
OBD2 141–142
OBD2 signal protocols 51–52
OBD3 147
On-board diagnostics 50, 119–149
future developments 147–149
diesel engines 148
model-based development 148–149
rate-based monitoring 148
history 119–127
misf re detection 135–140
P-code composition 125–126
petrol/gasoline on-board diagnostic monitors 127–135
technology of current systems 144–145
vehicle emissions and environmental health 119–120
Optical sensors 91–92
Oscilloscopes 47–50
typical waveforms 59
waveforms 49–50
Oxygen sensors 84–87
Titania 85–86
Zirconia 86–87

P

P-code composition 125–126
Petrol/gasoline on-board diagnostic monitors 127–135
adaptive fuel strategy in operation 132
catalyst monitor 128
circuit testing 128
component monitoring 127–128
evaporative system monitor 129–130
exhaust gas recirculation monitor 132–133
fuel system monitoring 130
legislative drivers 127
monitors and readiness f ags 134–135
rationality testing 128
rich AFR lambda sensor signal fuelling error 131
secondary air monitor 133–134
upstream and downstream exhaust gas sensor 129
Piezo accelerometer 82–84
Power-assisted steering 275
electric power steering 276
Pressure sensors 87–89
fuel pressure 89
manifold absolute pressure 89
strain gauges 87–88
Pressure testing 62–65
compression tester 64
fuel pressure gauge kit 64
running compression waveform 65

R

Rain sensors 93, 94
Relative compression petrol 112–113
Report writing 4–7
Risk assessment and reduction 2–3
Road speed sensor 82
Road test 19–20
Root cause analysis 13–15

S

Safe working practices 2
Scanners 50–59
Screen heating 364
Scrub radius 279–280
Seat belt tensioners 374
diagnostics 375
Seat heating 364
Security systems 338
diagnostics 339–342
Sensors 67–93
ABS speed sensor 72
ABS speed sensor waveform 73
airf ow meter-air vane 76–77
airf ow meter-hot wire 78
analogue MAP sensor 90
camshaft 70–72
crank and cam sensor output signals 71
crankshaft 70–72
diagnostics 67–69
digital MAP sensor 90
hall effect crank sensor 71
hot wire airf ow 77–78
hot wire air mass meter 78
inductive 69–74
inductive distributor pick-up 72–74
inductive pick-up output signal 74
Lambda sensor in exhaust downpipe 85
oil quality 90–91
throttle position potentiometer 75–76
variable resistance 74–77
Serial port communications 50
Spark plugs 109, 177–179, 183–184
condition 183–184
Springs 290, 291
SRS 374
Starter circuit 243
Starting 243
circuit and engagement mechanism 246
circuit testing procedure 248
diagnostics 248
fault diagnosis table 248–249
inertia 243
keyless system 247–248
permanent magnet 245–246
pre-engaged starters 244–245

Steering
 camber 277
 castor 277–278
 diagnostics 280
 four-wheel alignment 281
 scrub radius 279–280
 swivel axis inclination 278–279
 systemic testing 280
 test equipment 280
 tracking 279
 tracking gauges 281
 wheel balancer 281, 282
Steering box and rack 274–275
Steering characteristics 276–277
Stethoscope 385
Strain gauges 87–88
Strain gauges accelerometer 92
Suspension 286
 active 284
 anti-roll bar 289–290
 control system 299
 dampers 390
 Delphi MagneRide 297–299
 diagnostics 293, 299
 fault diagnosis 294
 front axle 288
 front struts 288
 front wishbone system 287
 springs 290, 291
 systematic testing 293, 299
 test equipment 293
Systems 34–36
 block diagrams 36
 closed-loop 35–36
 open-loop 35
 vehicle systems 34–35

T

Terminology 2–4
Test equipment
 accuracy 43–44
Test lights 22
Thermistors 78–80
 coolant temperature sensor 79–80
Tools 43–65
Torque converter operation 388–389
Tracking 279
Traction control 271
 diagnostics 272
 fault diagnostics table 274
 systematic testing 272
Transmission
 diagnostics 385
 electronic control 391–393
 test equipment 395
 test results 385
Transmission systems 379
Trip computer 355
Tyres 274
 diagnostics 280
 fault diagnosis 285
 functions 274
 inf ation pressures 284
 pressure gauge 280
 systematic testing 280
 test equipment 280
 test results 283
 tread depth gauge 280

V

Valve and ignition timing 155–156
Variable capacitance 89–91
Vehicle condition monitoring 353–355
Ventilation 359
 fault diagnosis table 367
Vibration conditions 19
Volt drop testing 24

W

Waveforms 49–50
Wheel balancer 281, 282
Wheel bearings 381
 front 383
 rear 383
Wiper circuits 327–328
Wiper motor and circuit
 testing 334, 335
Wiper motors and linkages 325–326
 two-motor system 328